Embodiment and Integrated Task and Motion Planning for Human-Centered Robots

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The Human Centered Robotics Lab

Aerospace Engineering

The University of Texas at Austin

Winter School, Toulouse, Dec. 5 2016

Biogerontechnology and Assistive Technologies (source: Fatronik 2007)

Age	%disabled
60	13%
70	22%
80	42%
90	65%

Picture from Google search

<u>Human Centered Robotics</u>:
The study of machines and robotic systems…

… with high mobility and sensing to assist, augment, or represent humans…

… in any way that will increase productivity, security, health and social comfort.

Google

human centered robotics

All News Images Videos Shopping More Search tools

About 323,000 results (0.56 seconds)

Scholarly articles for **human centered robotics**

Human-centered robotics applied to gait training and … - Riener - Cited by 99

Intelligent space and **human centered robotics** - Yamaguchi - Cited by 67

Human-centered robotics and interactive haptic … - Khatib - Cited by 60

The Human Centered Robotics Group – Decision and Control of ...
sites.utexas.edu/hcrl/
21 Sep 2016 - We are very pleased to have an all star line up of keynote speakers for the IEEE International Workshop of Advanced **Robotics** and its Social ...
People · Publications · Research · Courses

Human-Centered Robotics Lab - University of Washington
https://hcrlab.cs.washington.edu/
Human-Centered Robotics Lab Computer Science & Engineering Department | University of Washington. ; ,. Faculty. Graduate Students. Visitors ...

Brown University Humanity Centered Robotics Initiative – The next ...
https://hcri.brown.edu/
"Malle suspects that we might actually want our **robots** to make different decisions than the ones we'd want other **humans** to make . . .[in a life or death scenario] ...

NASA Technical Memorandum 86856

Human Factors in Space Station Architecture II

EVA Access Facility: A Comparative Analysis of Four Concepts for On-Orbit Space Suit Servicing

Marc M. Cohen
Ames Research Center

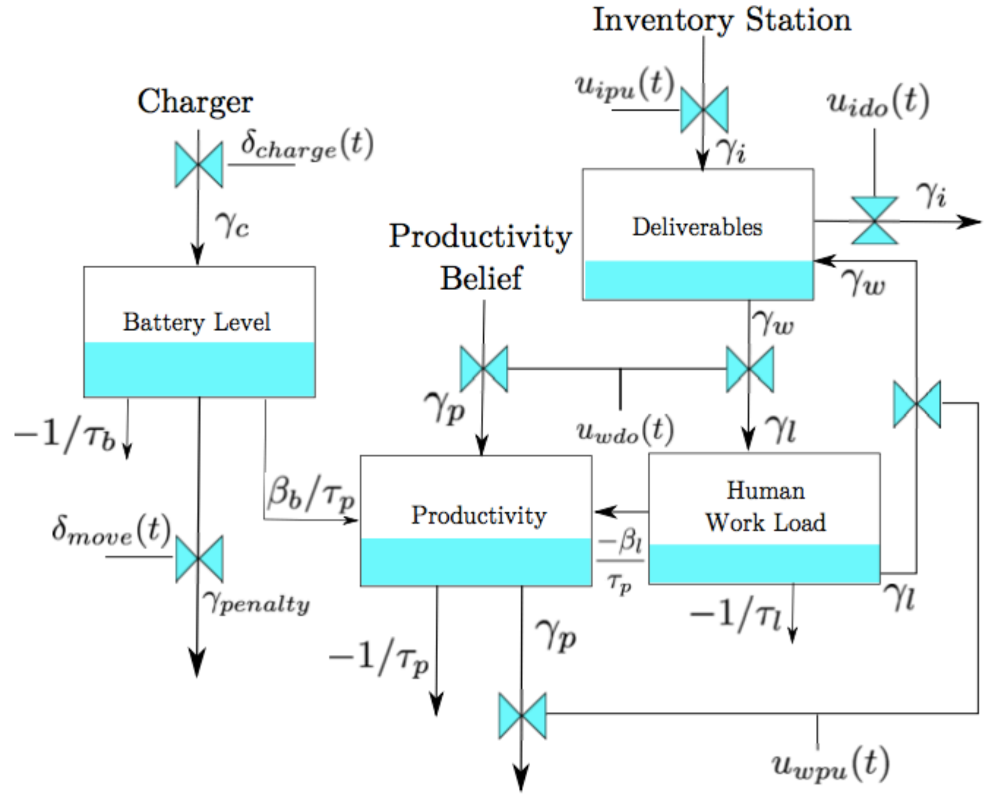
the Skylab mission (ref. 2).

Since 1982, the Space Transportation System (STS) places increasing emphasis upon the regular use of EVA for in-flight development, recovery, and repair of space systems. This trend is expected to continue on the Space Station. The dexterity of the human operator in EVA is transmitted through the human/machine interface imposed by the protective envelope of the suit; hence, significant advances in EVA capability are due primarily to improvements in the design of the space suit. The primary goal of space suit design is to reduce losses in human dexterity and in mobility to the

*Massachusetts Institute of Technology, Cambridge, MA.

Disney Co.

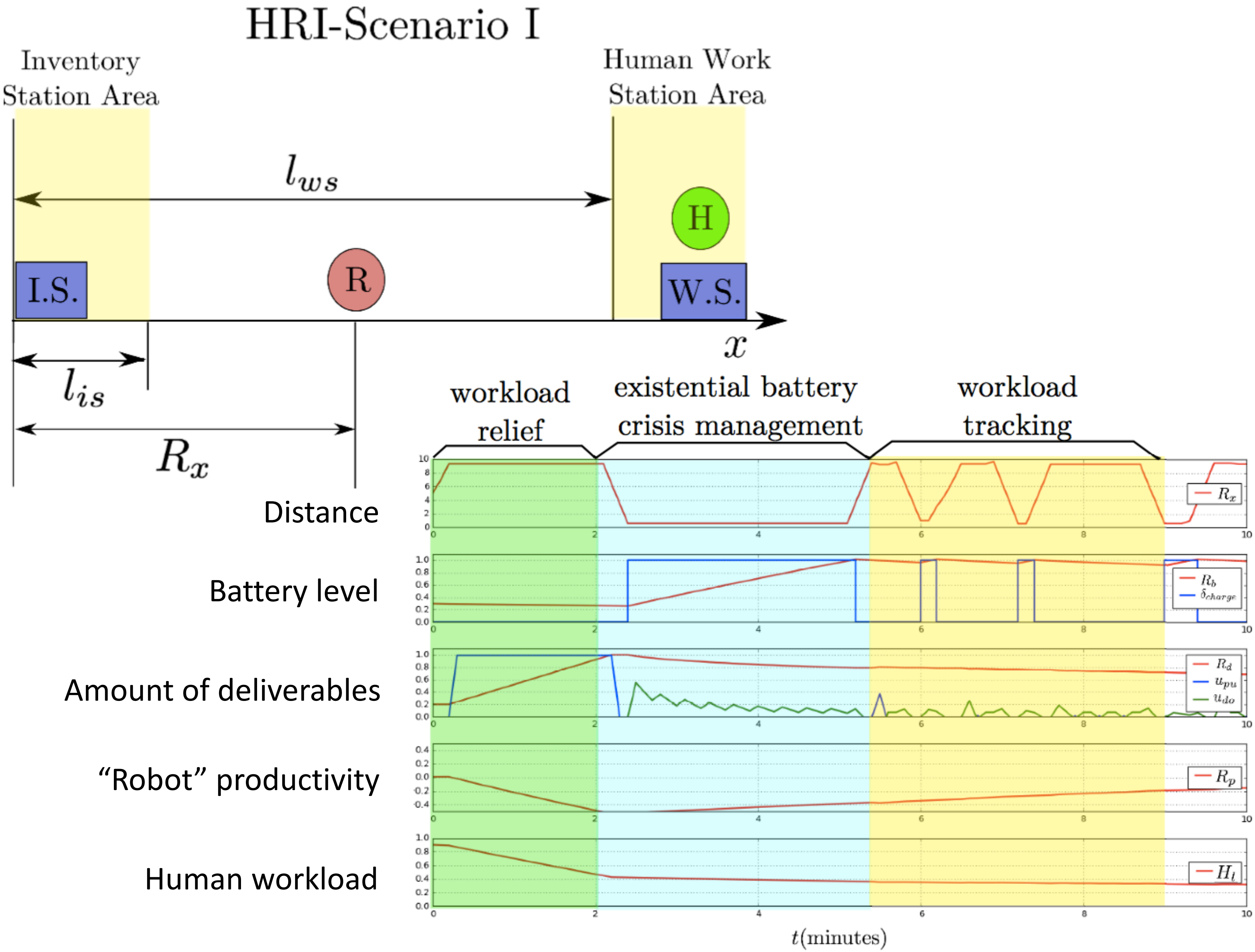
The University of Texas at Austin



References:

W. T. Riley, D. E. Rivera, A. A. Autienza, W. Nilsen, S. Allison, and R. Mermelstein, Health behavior models in the age of mobile interventions: are our theories up to the task? *Translational Behavioral Medicine: Practice,* 2011

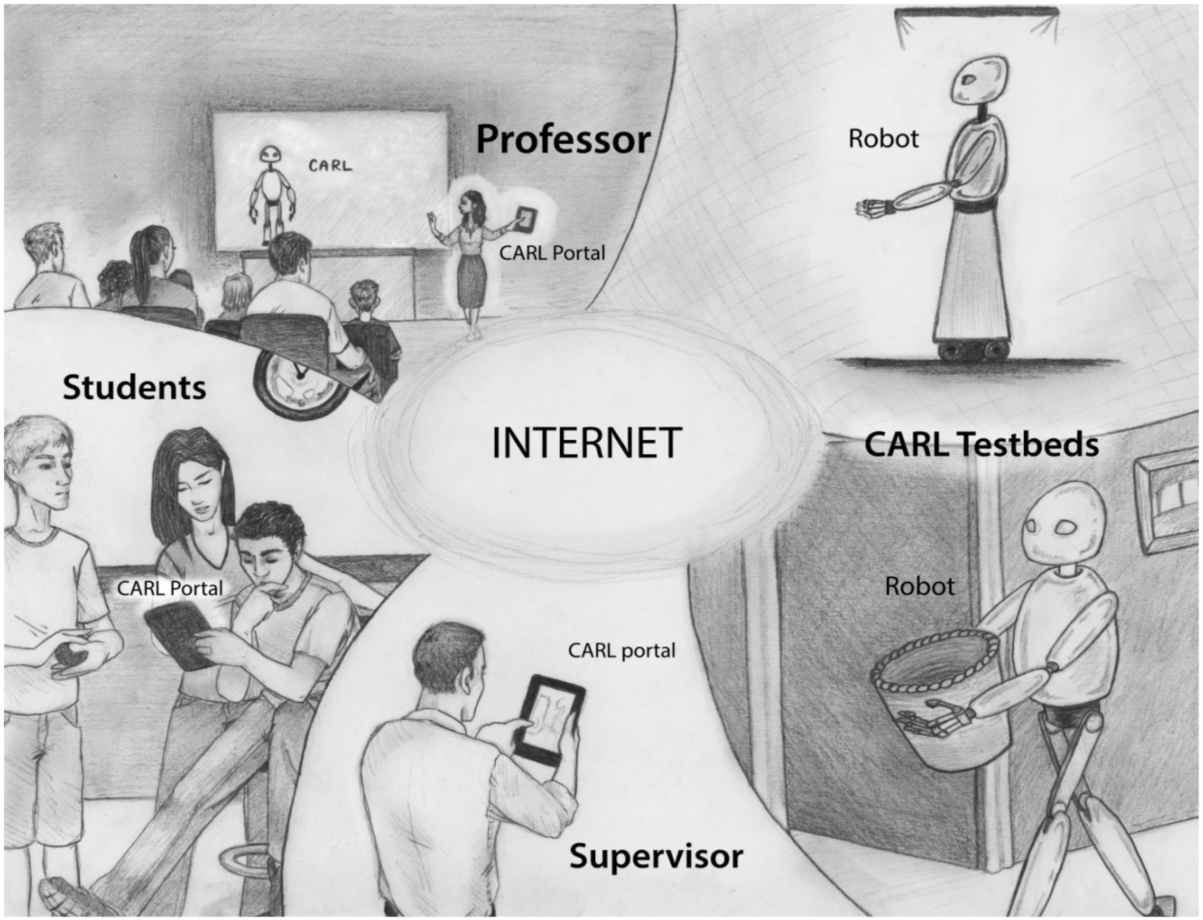
A. Martin, D. E. Rivera, W. T. Riley, E. B. Hekler, M. P. Buman, M. A. Adams, and A. C. King. A Dynamical Systems Model of Social Cognitive Theory, *American Control Conference*, 2014.



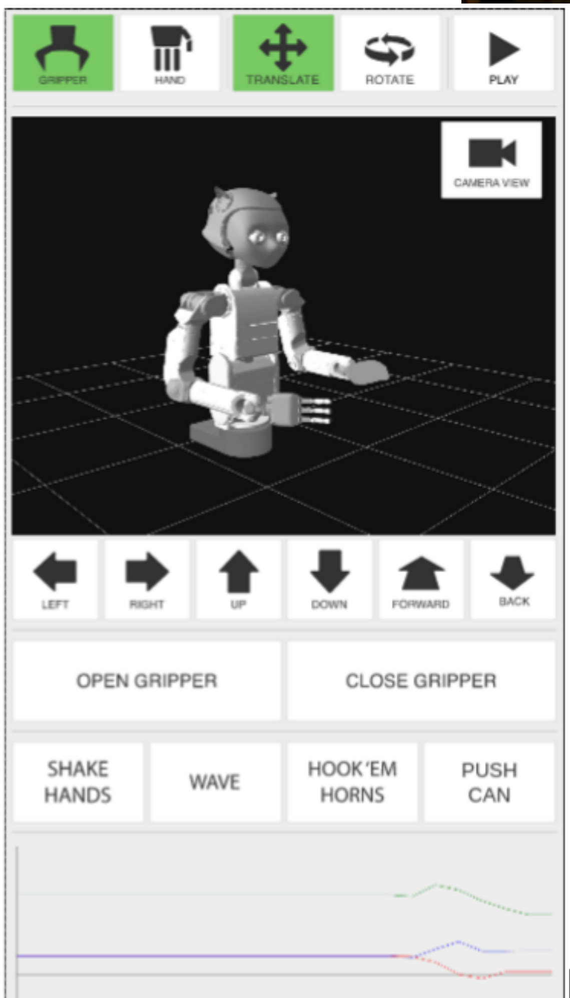
(b) 30% Robot battery & 90% human workload at t= 0

Dreamer means: No, I don't know you

2014 Concept on Shared Equipment

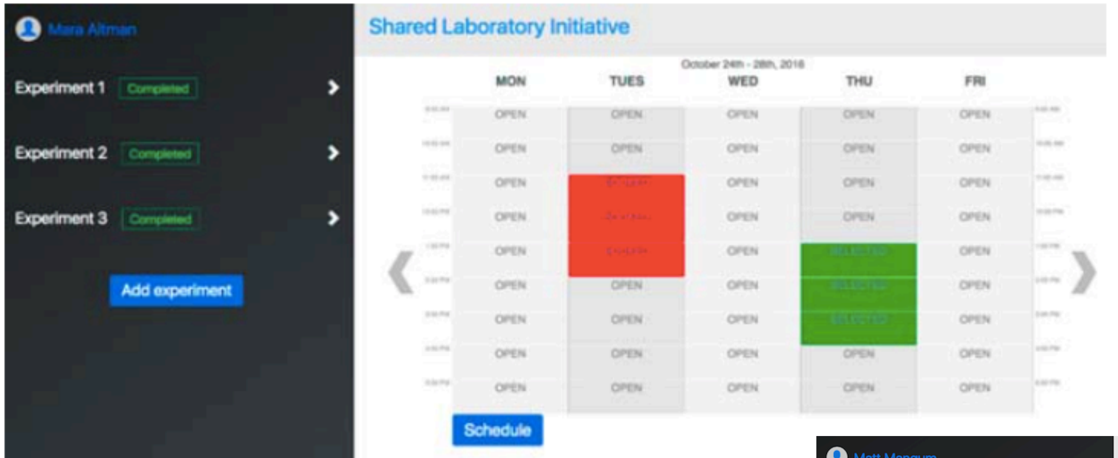


C.L. Fok, F. Sun, M. Mangum, A. Mok, B. He, L. Sentis, Web Based Teleoperation of a Humanoid Robot, arXiv:1607.05402 [cs.RO]

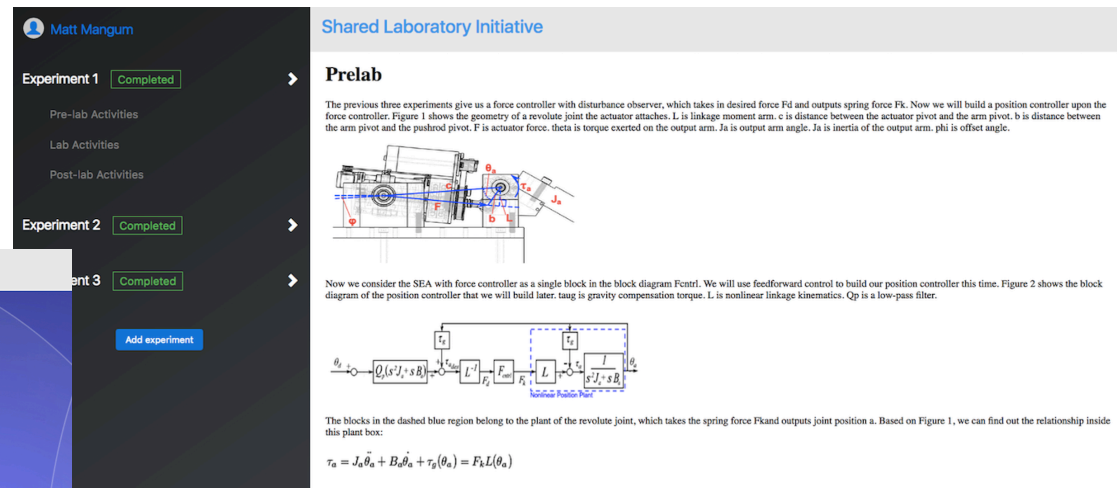


Democratizing ~~Robots~~ Devices via Smart and Shared Educational Content

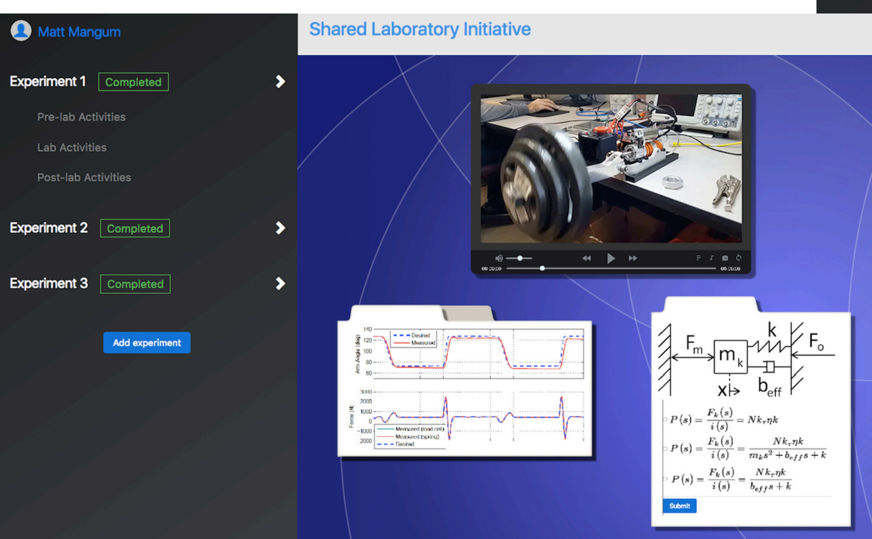
Snapshots



Mara Altman
Shared Laboratory Initiative
Experiment 1 Completed
Experiment 2 Completed
Experiment 3 Completed
Add experiment
October 24th - 28th, 2016
MON
TUES
WED
THU
FRI
OPEN
Schedule

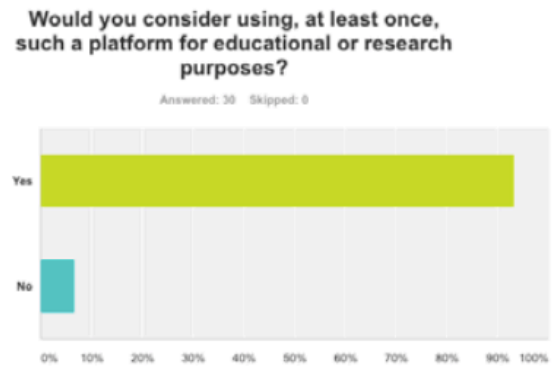


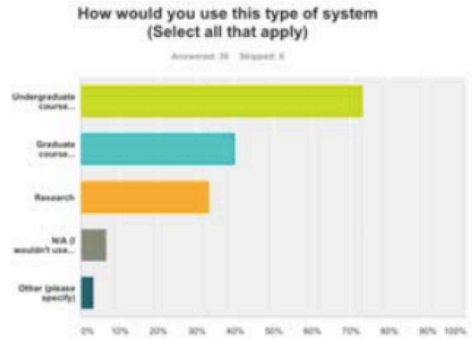
Matt Mangum
Shared Laboratory Initiative
Experiment 1 Completed
Pre-lab Activities
Lab Activities
Post-lab Activities
Experiment 2 Completed
Experiment 3 Completed
Add experiment
Prelab
The previous three experiments give us a force controller with disturbance observer, which takes in desired force Fd and outputs spring force Fk. Now we will build a position controller upon the force controller. Figure 1 shows the geometry of a revolute joint the actuator attaches. L is linkage moment arm. c is distance between the actuator pivot and the arm pivot. b is distance between the arm pivot and the pushrod pivot. F is actuator force. theta is torque exerted on the output arm. Ja is output arm angle. Ja is inertia of the output arm. phi is offset angle.
Now we consider the SEA with force controller as a single block in the block diagram Fcntrl. We will use feedforward control to build our position controller this time. Figure 2 shows the block diagram of the position controller that we will build later. taug is gravity compensation torque. L is nonlinear linkage kinematics. Qp is a low-pass filter.
Nonlinear Position Plant
The blocks in the dashed blue region belong to the plant of the revolute joint, which takes the spring force Fkand outputs joint position a. Based on Figure 1, we can find out the relationship inside this plant box:
$\tau_a = J_a\ddot{\theta}_a + B_a\dot{\theta}_a + \tau_g(\theta_a) = F_k L(\theta_a)$

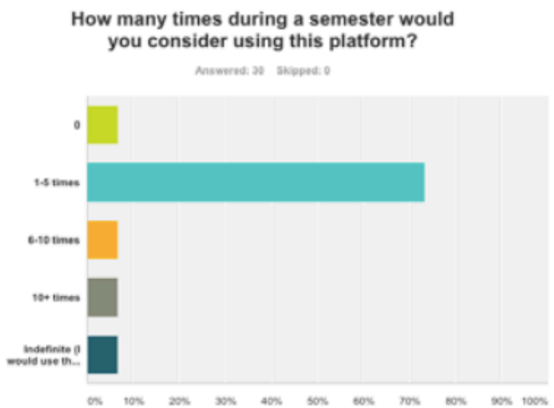


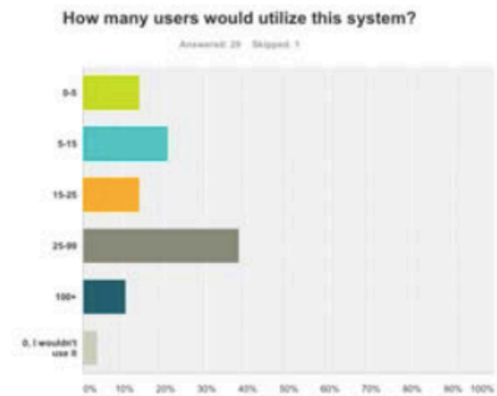
Matt Mangum
Shared Laboratory Initiative
Experiment 1 Completed
Pre-lab Activities
Lab Activities
Post-lab Activities
Experiment 2 Completed
Experiment 3 Completed
Add experiment
F_m
m_k
k
F_o
b_{eff}
$P(s) = \frac{F_k(s)}{i(s)} = Nk_\tau\eta k$
$P(s) = \frac{F_k(s)}{i(s)} = \frac{Nk_\tau\eta k}{m_k s^2 + b_{eff}s + k}$
$P(s) = \frac{F_k(s)}{i(s)} = \frac{Nk_\tau\eta k}{b_{eff}s + k}$
Submit

Surveys + Information eXperience

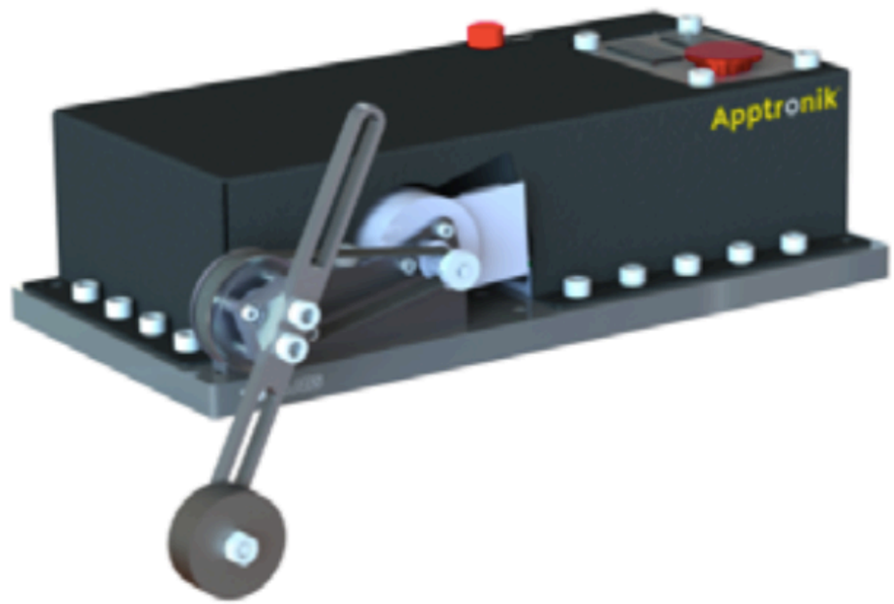


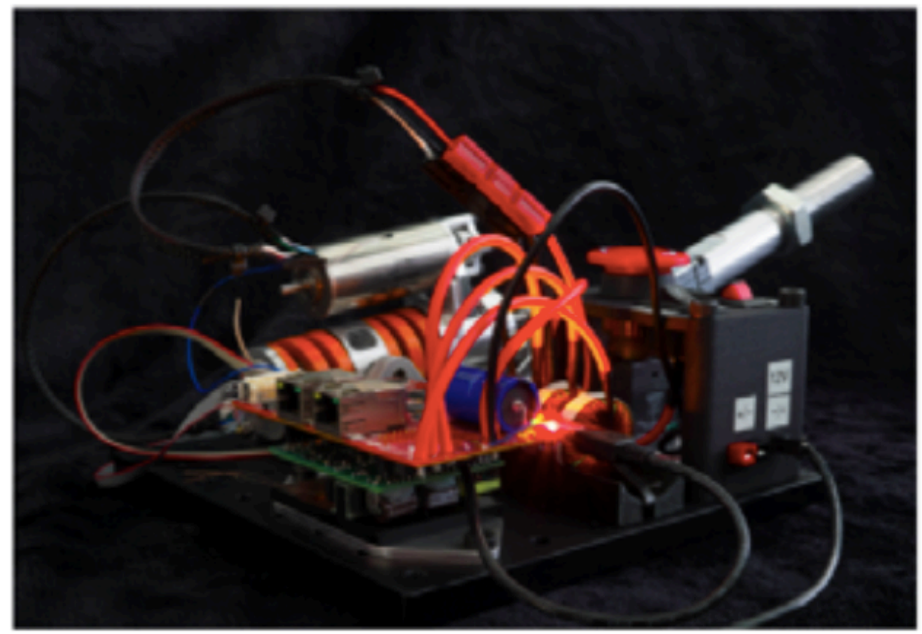






Apptronik's role





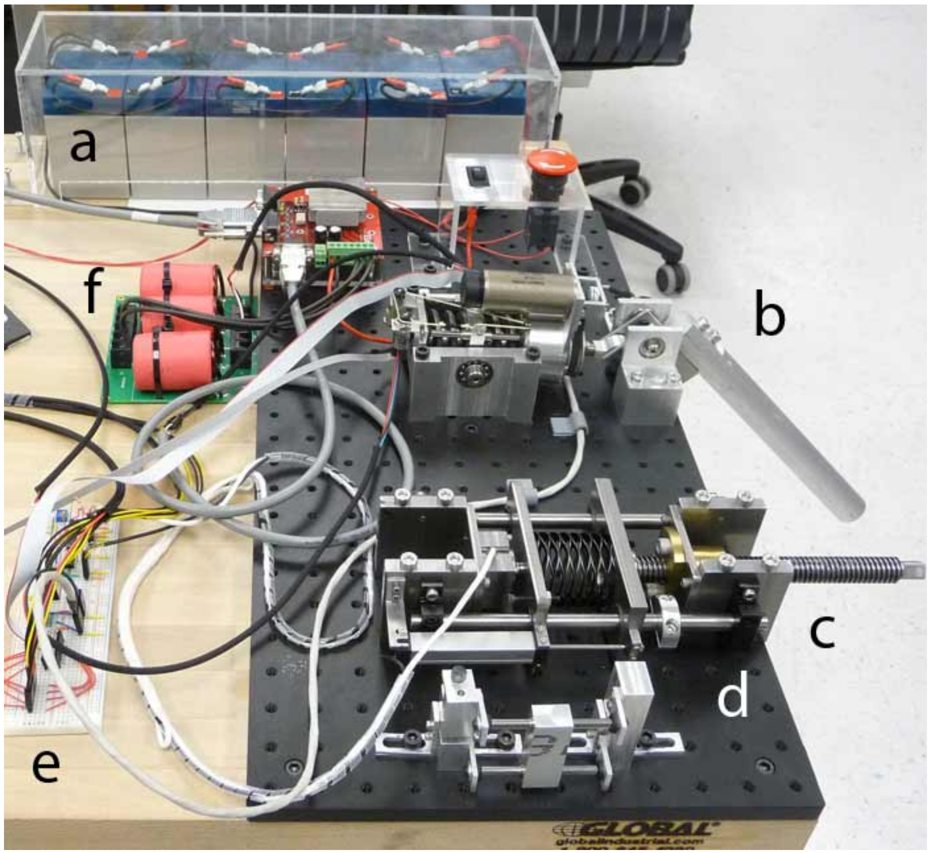
Course Decision and Control of Human-Centered Robots

WEEK	TOPIC
Th 8/25	Syllabus / Background / Introductions / Project Teaming
Week 8/30	Intro Autonomous Systems, Socio Cognitive Modeling of Human Activity
Week 9/6	Unconstrained and constrained optimization, 1st and 2nd Order Solvers, Lagrangian Multipliers, Optimal Control, Model Predictive Control (MPC)
Week 9/13	Socio-Cognitive Behavior Intervention via MPC, Mixed Integer Programming
Week 9/20	Case Study: Behavior Interventions on Exercising Activity
Week 9/27	Introduction to Sequential Composition, LQR-Trees Theory
Week 10/4	LQR-based Linearization along Trajectories, Regions of Attraction via SOS Tools, Case Study: Nonlinear Underactuated System Stabilization
Week 10/11	Intro to Motion Planning with LTL Specifications, Lifted Graphs, Admissible Paths, Intro to Linear Temporal Logic
Week 10/18	Transition Systems Incorporating Geometric and Temporal States, Mission Compliant Paths, Intro Automata Theory
Week 10/25	Nonlinear Controller Synthesis and Automatic Workspace Partitioning for Reactive High-Level Behaviors
Week 11/1	Intelligent Collision Management in Human-Centered Robots
Week 11/8	Provably Safe Obstacle Avoidance for Autonomous Robotic Ground Vehicles
Week 11/15	Stabilizing Series-Elastic Point-Foot Bipeds Using Whole-Body Operational Space Control, Integrated Task and Motion Planning
Week 11/22	Details ONR MURI Autonomous Systems, Thanksgiving Holiday
Week 11/29	**Final Project Presentations**

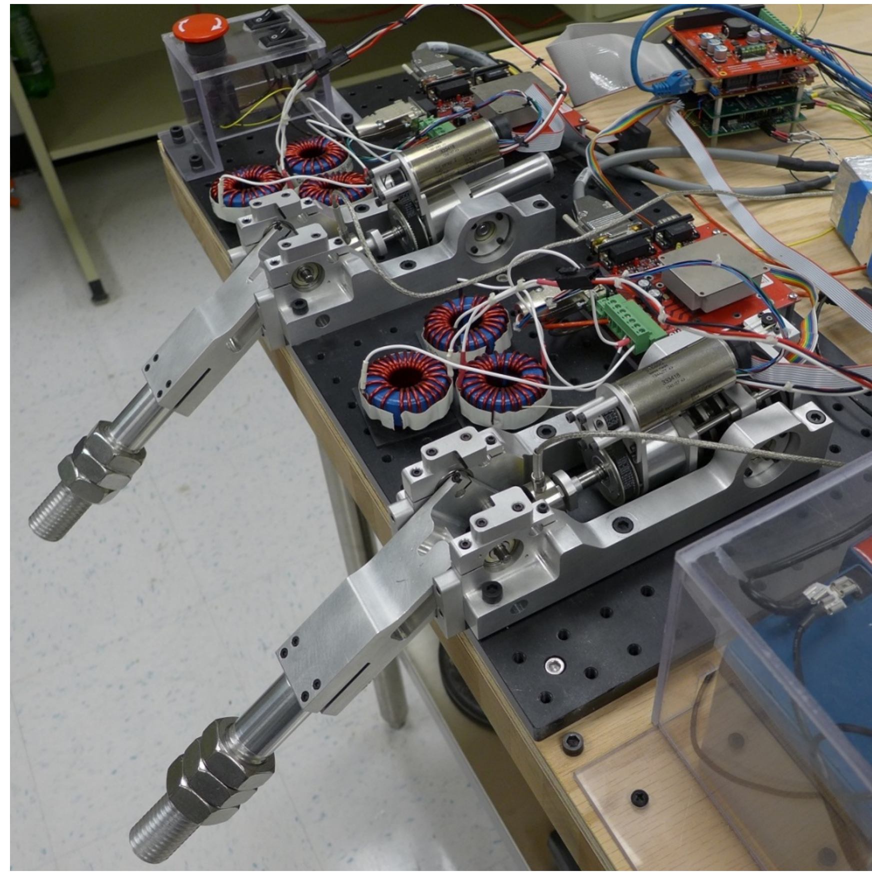
Let’s change topic... Embodiment

UT Testbeds

Original UT-SEA testbed



UT-SEA Version 2 testbed

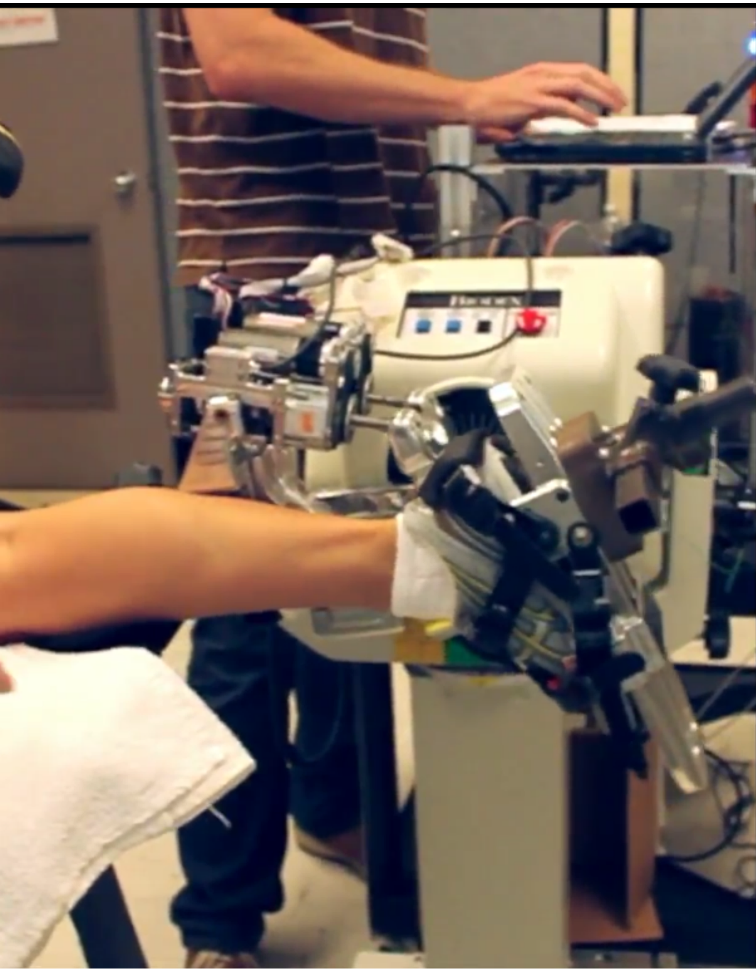


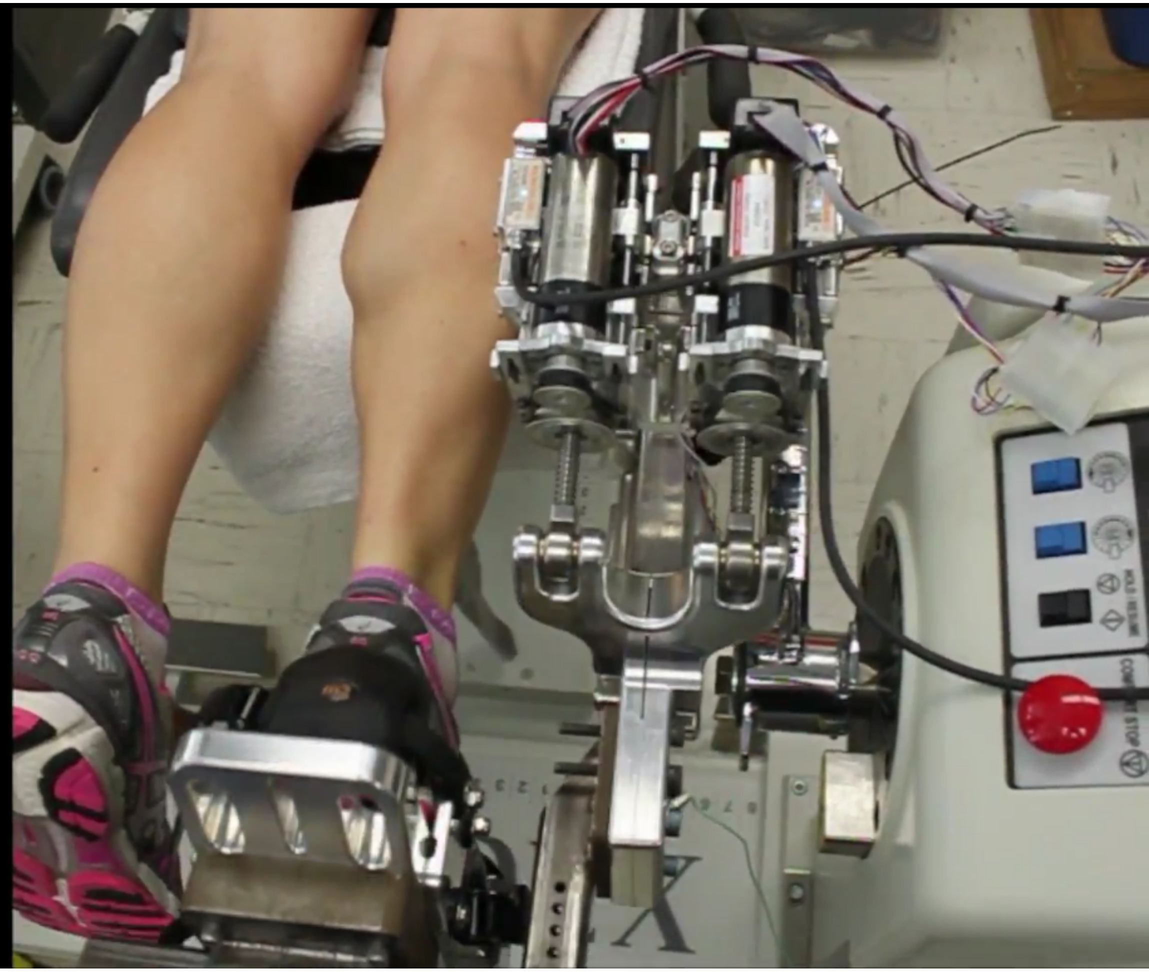
Specifications

UT-SEA Design Specifications		
Weight	1013 g	2.23 lbs
Stroke	6 cm	2.36 in
Max Speed	32.5 cm/sec	12.79 in/sec
Continuous Force	848 N	190 lbs
Intermittent Force	2800 N	629 lbs
Spring Stiffness	278 N/mm	1587 lbs/in
Force Resolution	0.31 N	0.069 lbs
Operating Voltage	80V	

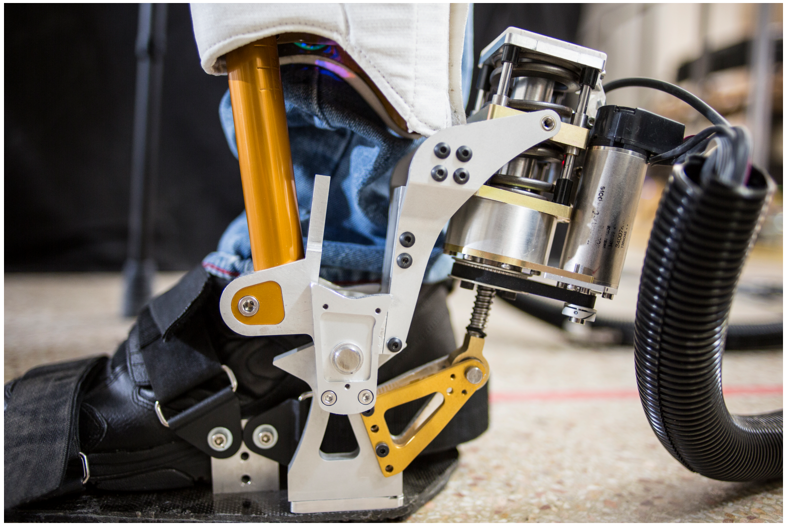
2013 adoption

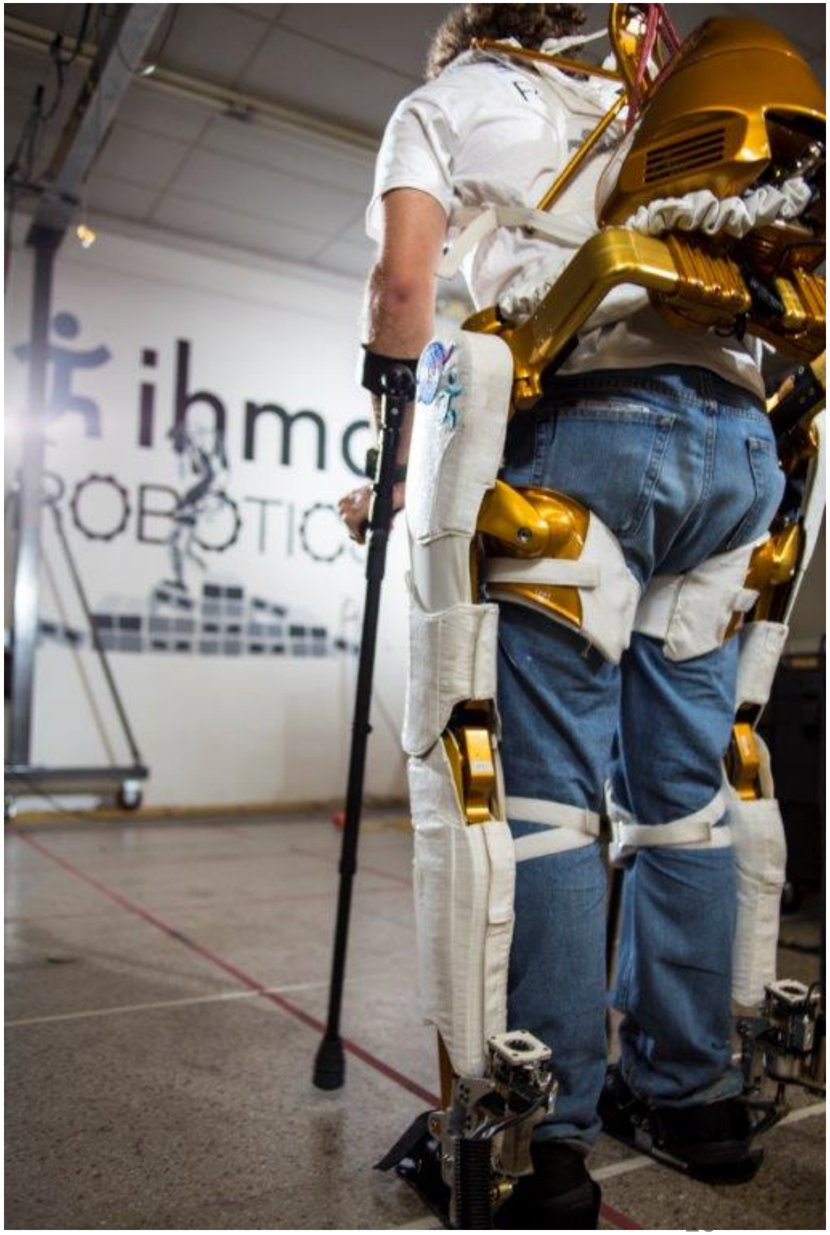
Rehabilitation Systems

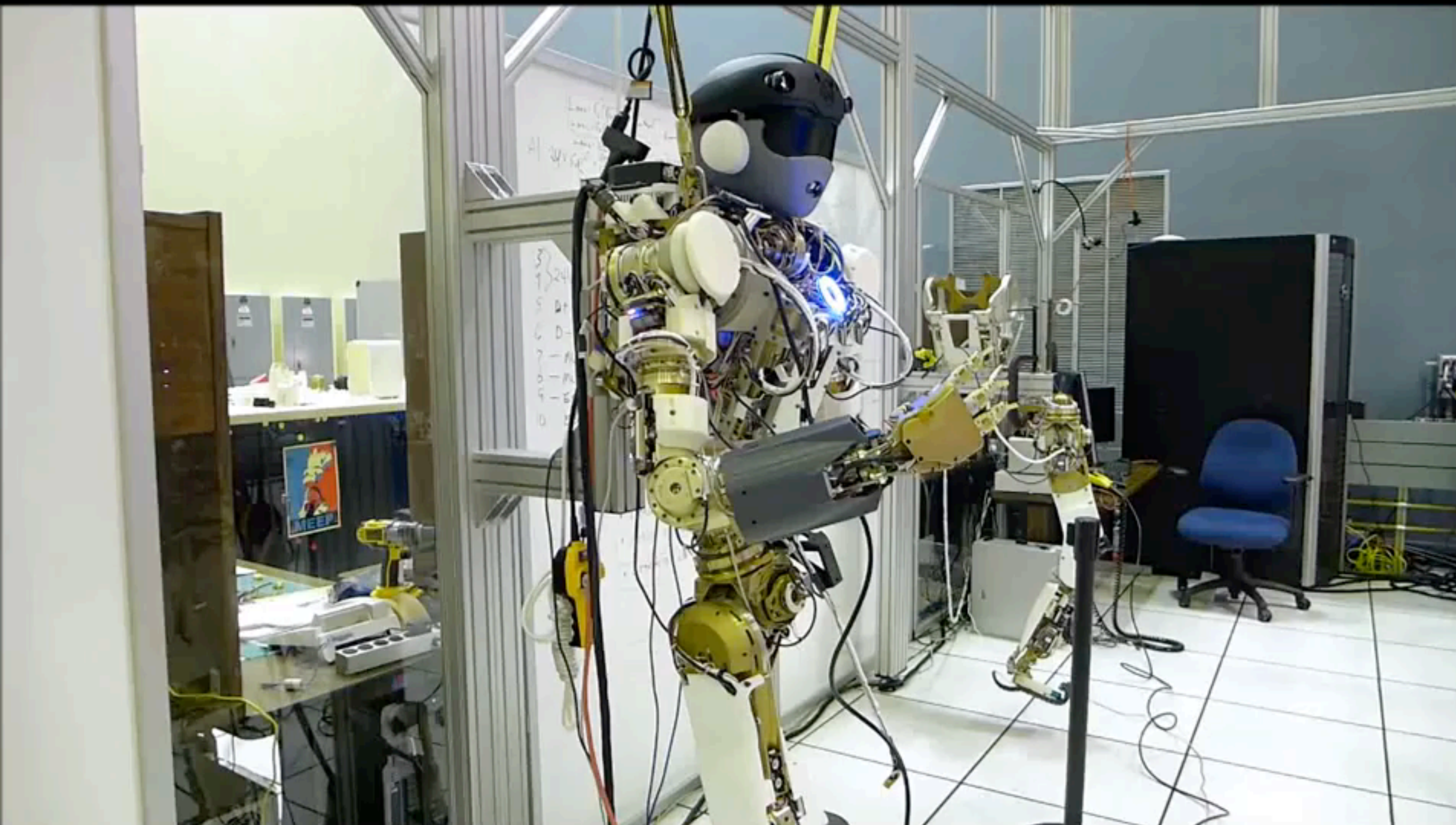




X1 Mina Exo

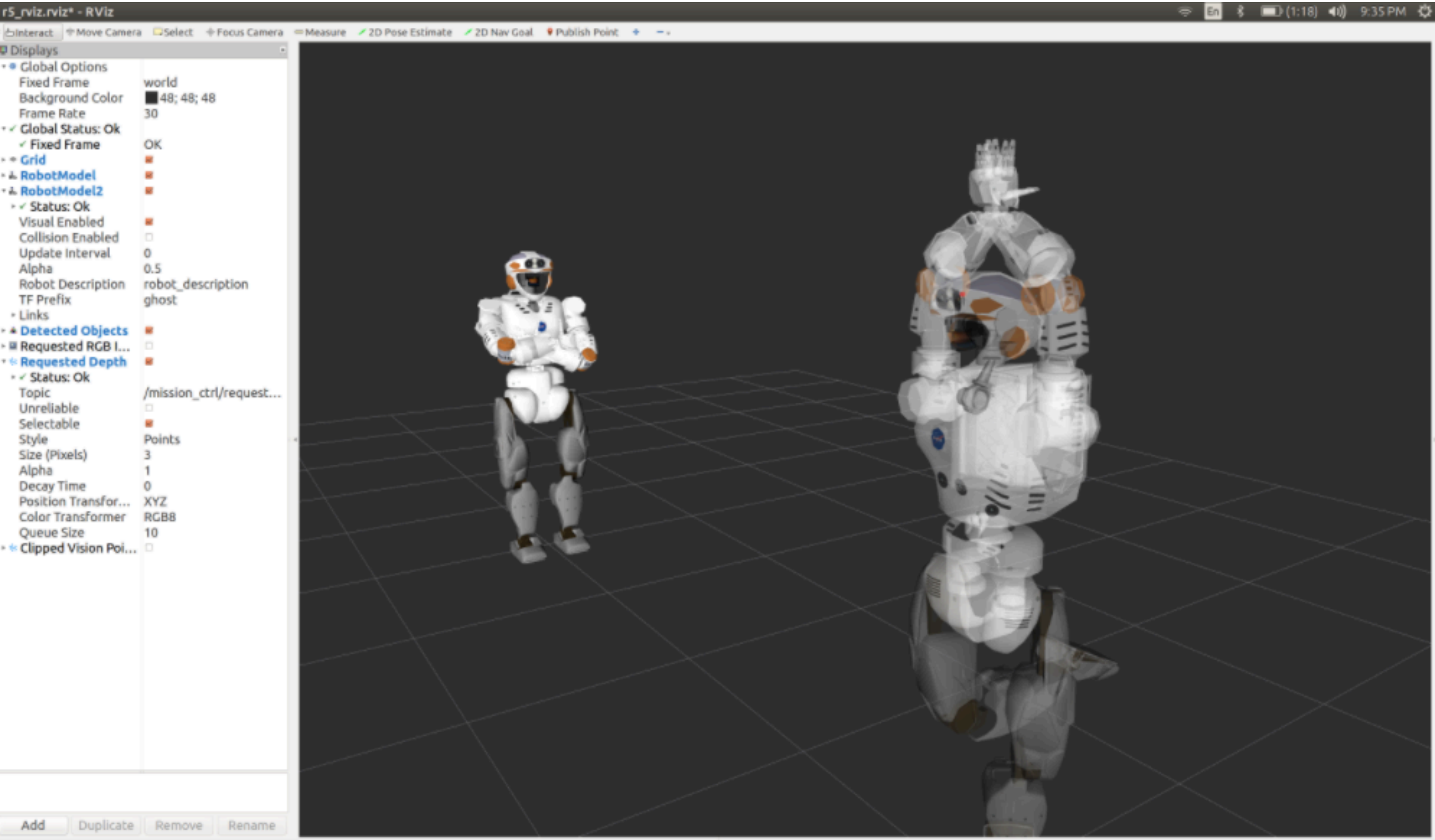




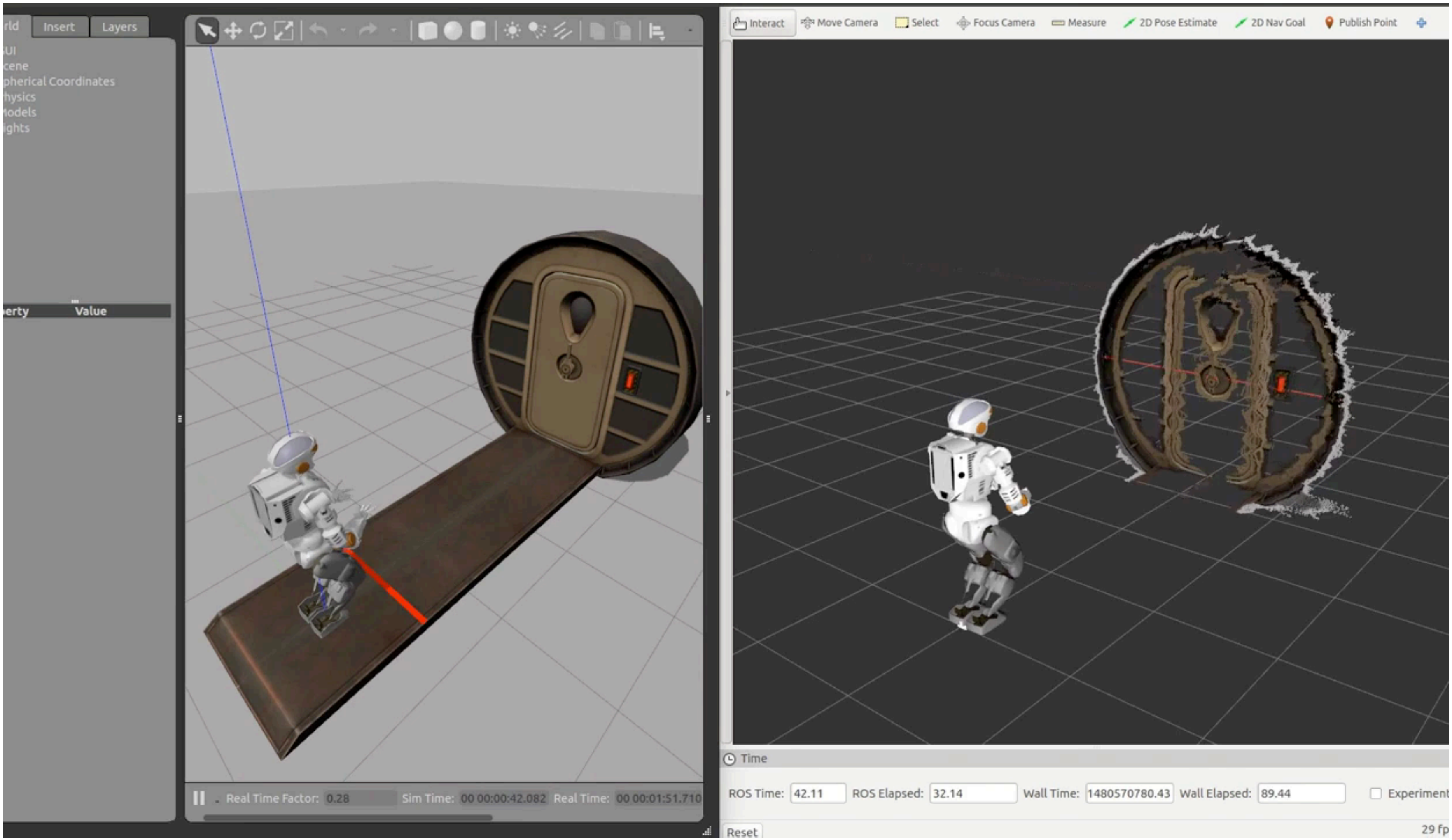

MEEP

Valkyrie Program

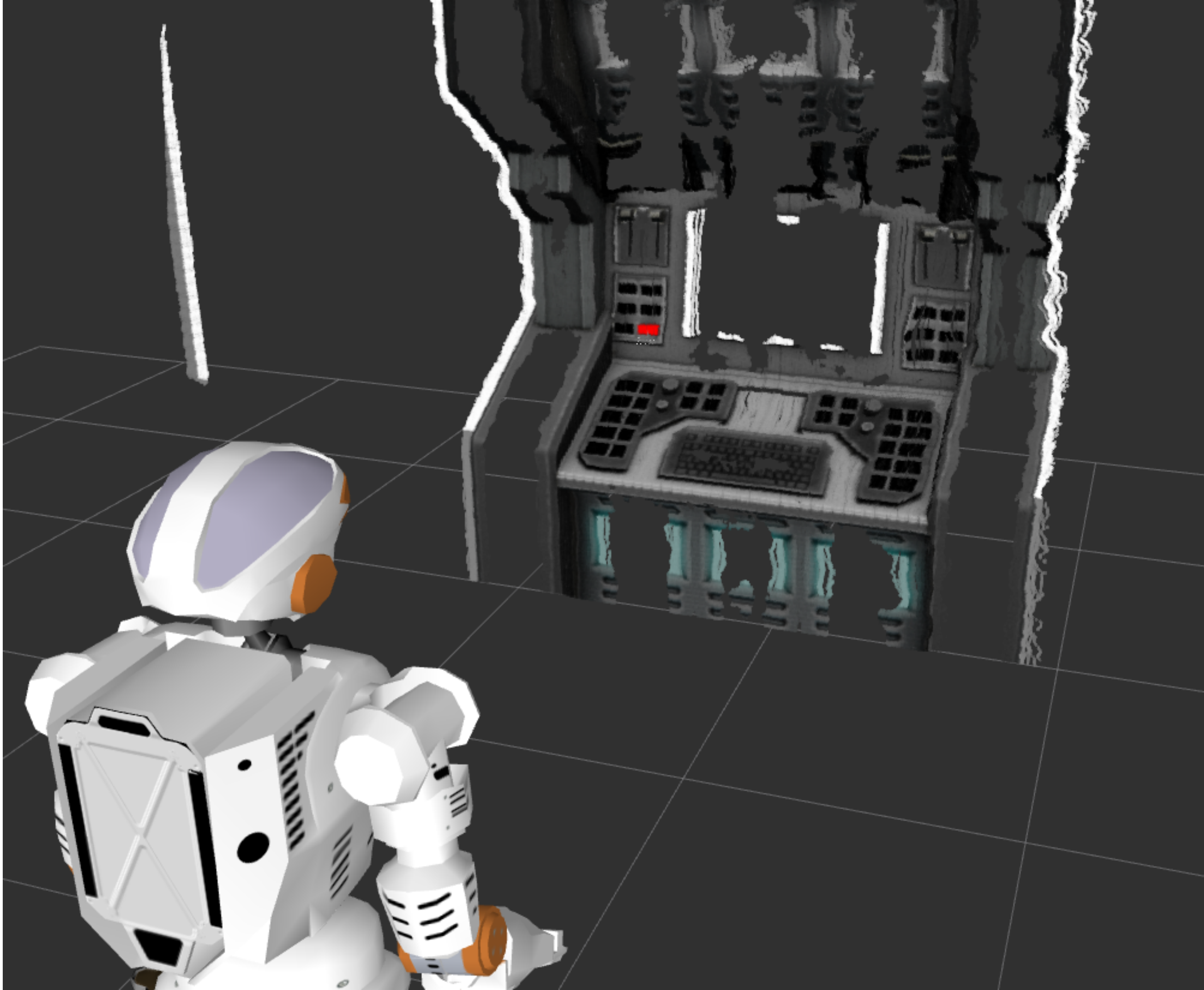
So, what are we doing today ;)



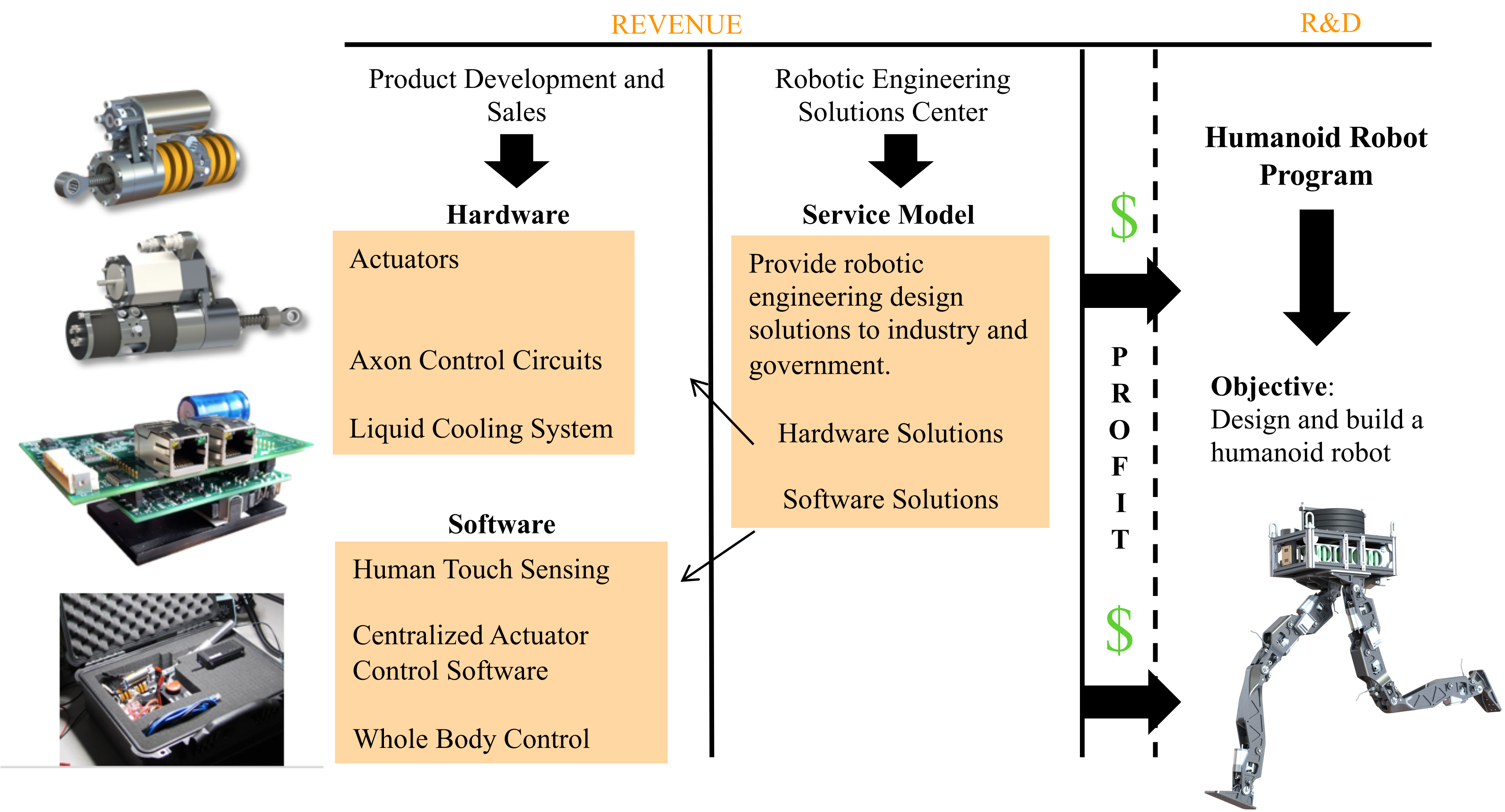
NASA Space Robotics Challenge

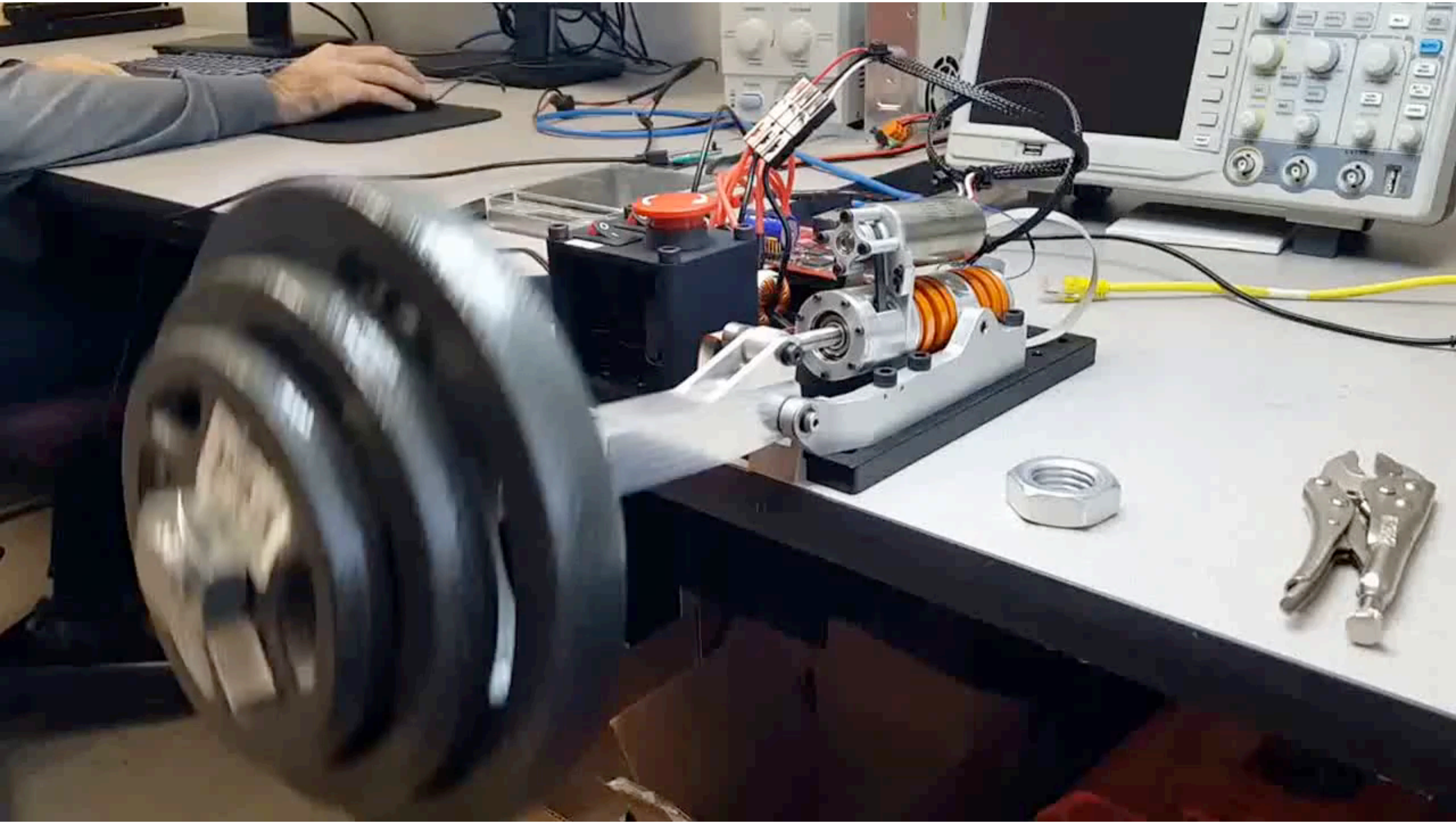


Mission 2 SRC: The Human Centered Robotics Lab + various UT Austin Students

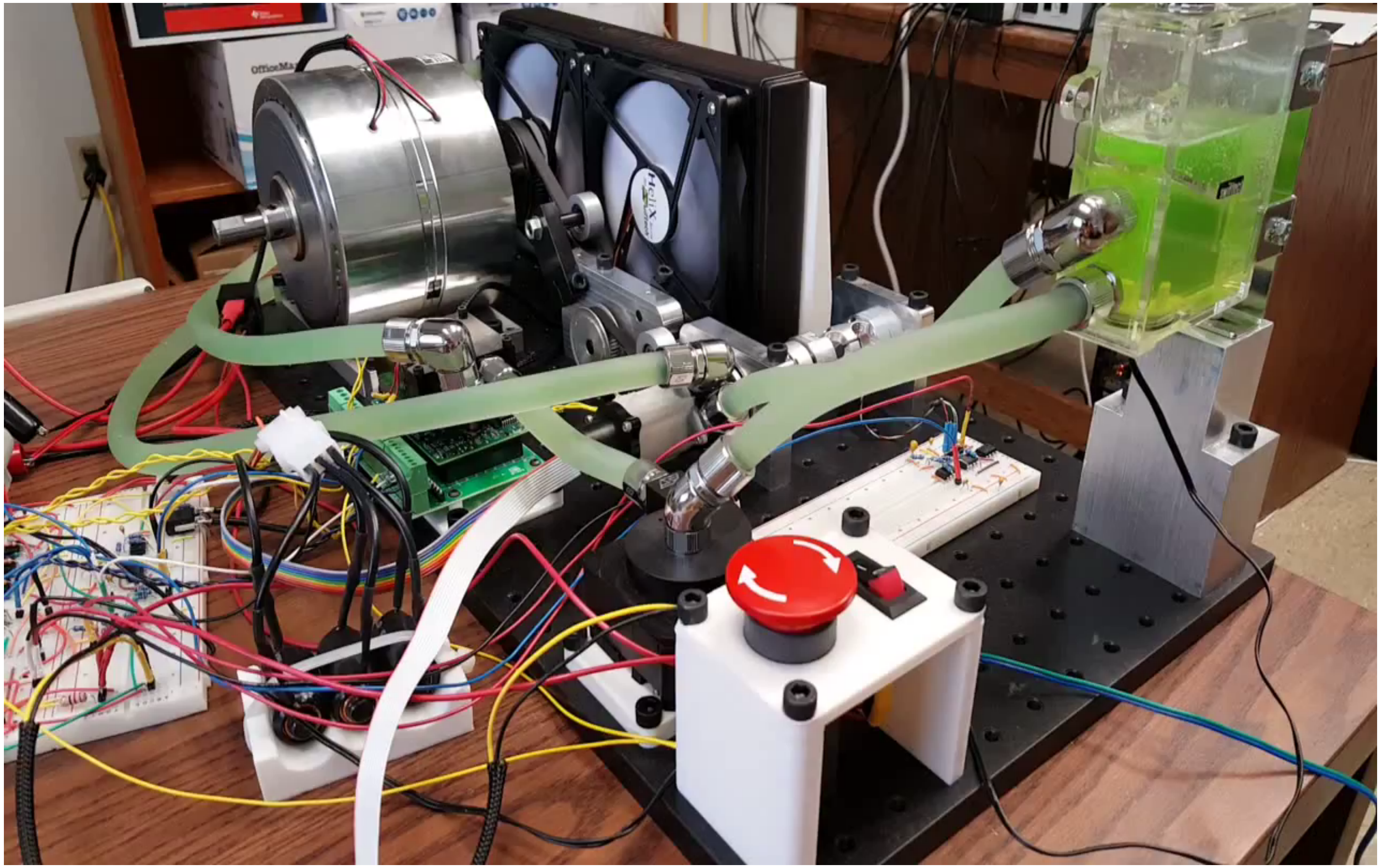


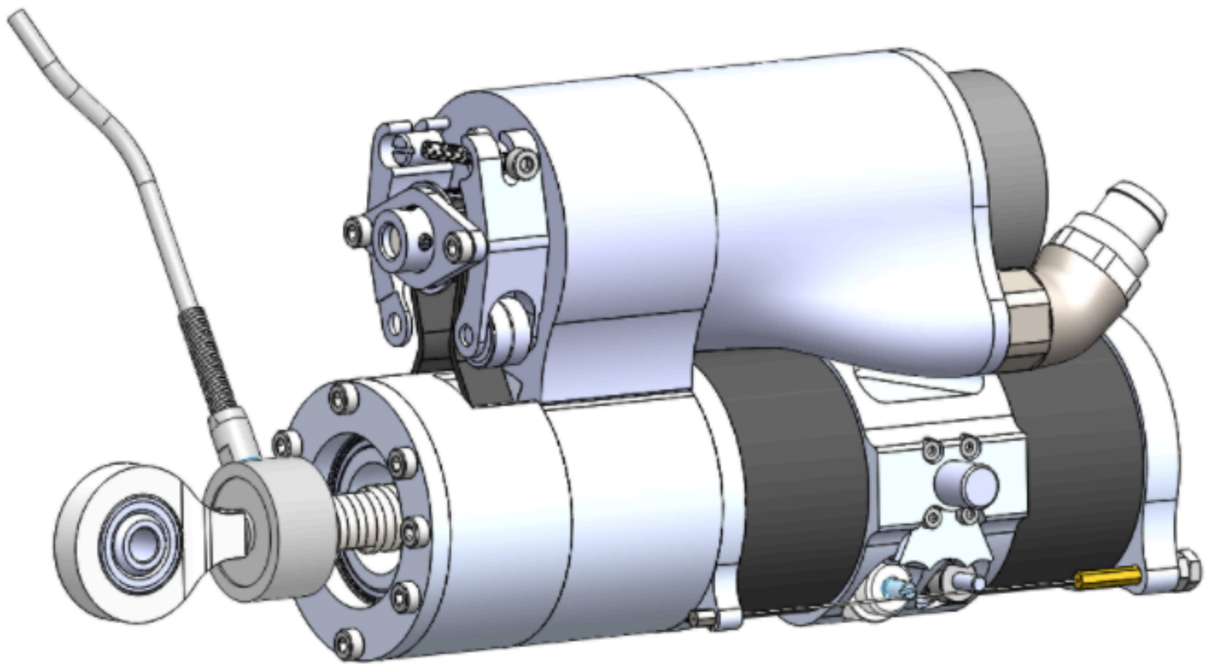
Apptronik


REVENUE
R&D
Product Development and Sales
Hardware
Actuators
Axon Control Circuits
Liquid Cooling System
Software
Human Touch Sensing
Centralized Actuator Control Software
Whole Body Control
Robotic Engineering Solutions Center
Service Model
Provide robotic engineering design solutions to industry and government.
Hardware Solutions
Software Solutions
$
PROFIT
$
Humanoid Robot Program
Objective: Design and build a humanoid robot



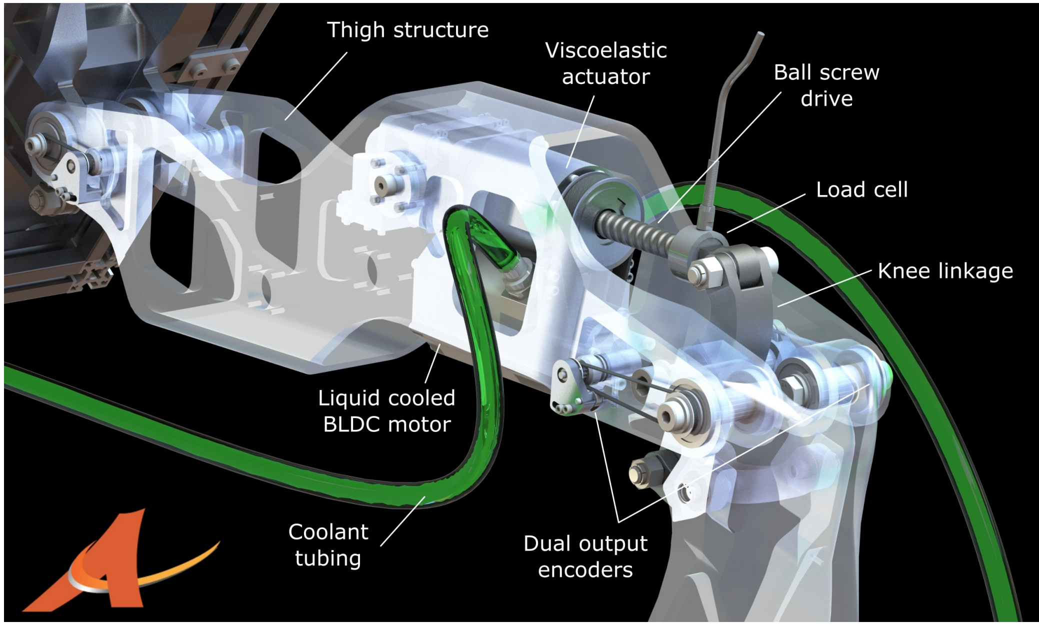
Building systems for agility



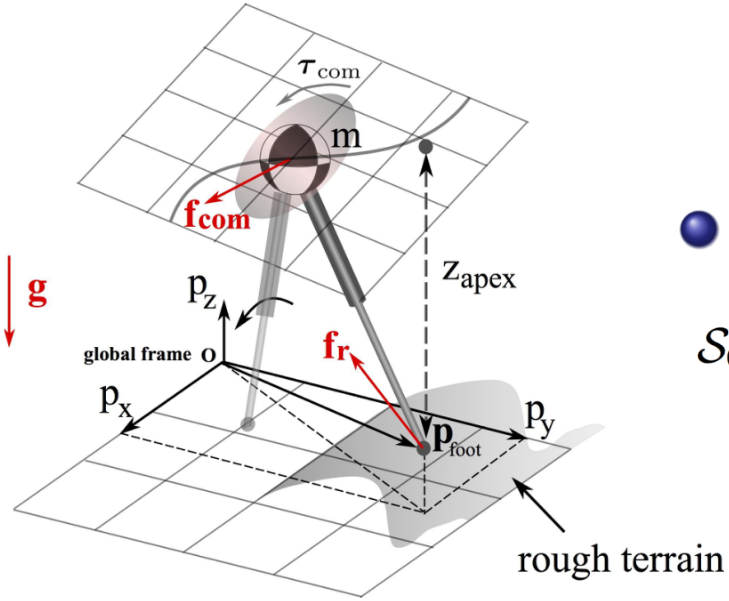


Liquid Cooled Viscoelastic Actuator

More to come


Thigh structure
Viscoelastic actuator
Ball screw drive
Load cell
Knee linkage
Liquid cooled BLDC motor
Coolant tubing
Dual output encoders

Agility is Key Interest... Dynamic Locomotion



- Center of mass surface manifold

$$\mathcal{S}_{\text{CoM}} = \left\{ (x, y, z) \in \mathbb{R}^3 \;\middle|\; \psi_{\text{CoM}}(x, y, z) = 0 \right\}$$

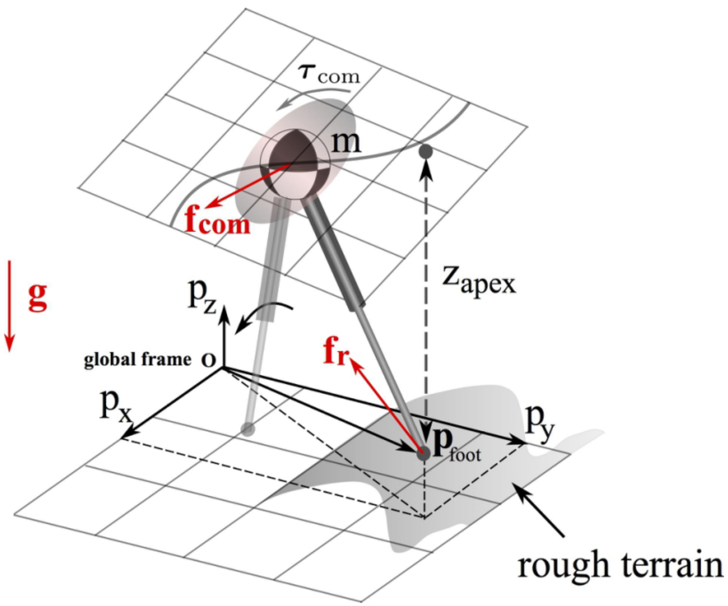
Output Dynamics of the Center of Mass

The prismatic inverted pendulum model for a q^{th} walking step, is represented by the following control system,

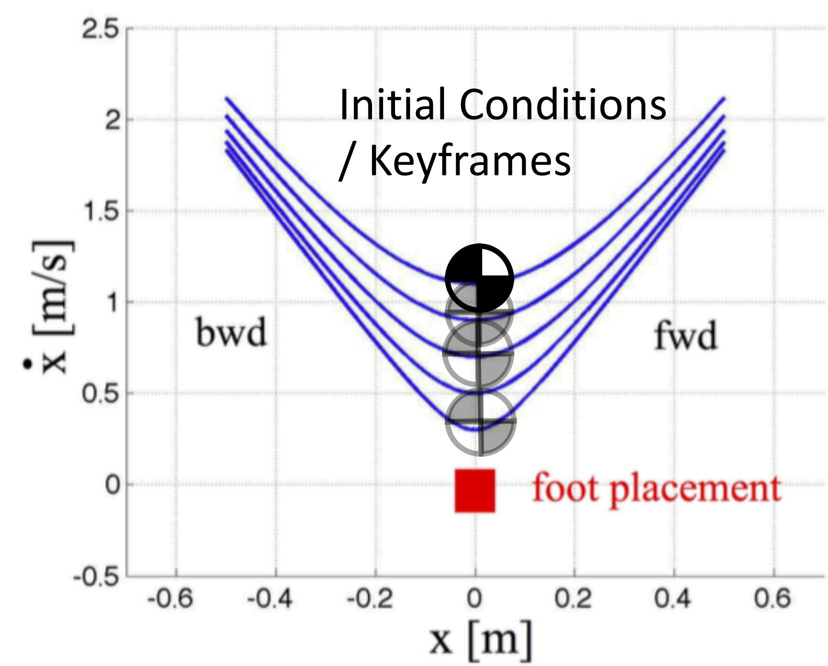
$$\dot{\boldsymbol{\xi}} = \boldsymbol{\mathcal{F}}(q, \boldsymbol{\xi}, \boldsymbol{u}) \qquad \text{(PIPM dynamics)}$$

where $\boldsymbol{\xi} = (x, y, z, \dot{x}, \dot{y}, \dot{z})^T, \boldsymbol{u} = (\omega, \boldsymbol{\tau}, \boldsymbol{p}_{\text{foot}})^T$.

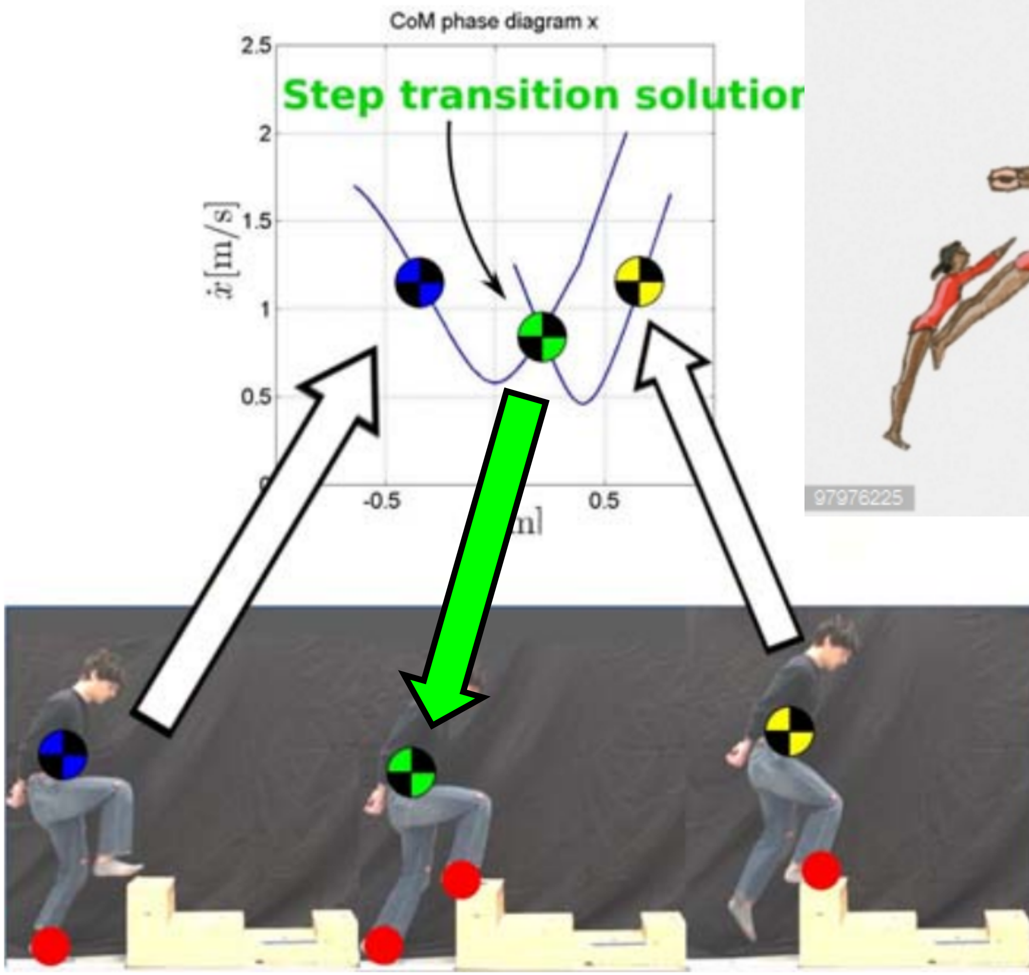
Keyframe states



Phase Portrait Center of Mass

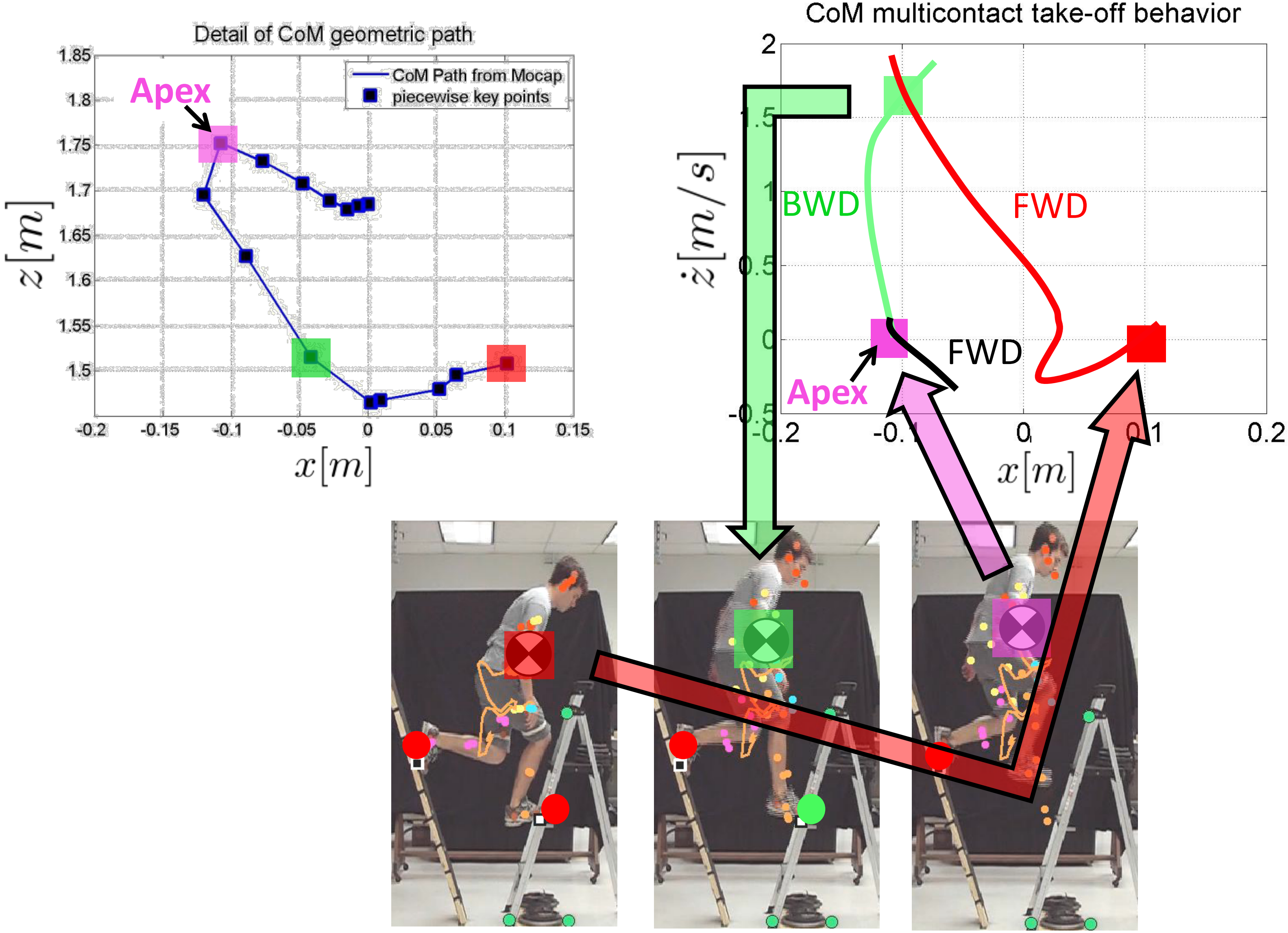


Motion planning

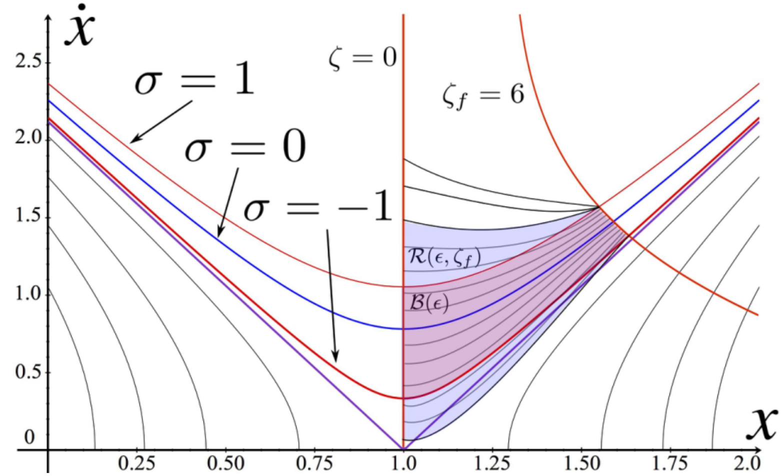


Like calculating the timing for bouncing in gymnastics… but simpler

Example: Extreme Maneuver from Human Demonstration



Tangent Manifold



$$\mathcal{M}_{\text{CoM}} = \left\{ \boldsymbol{x} \in \mathbb{R}^2 \;\middle|\; \sigma(\boldsymbol{x}) = 0 \right\}$$

Proposition: Phase-Space Tangent Manifold

Given desired PIP dynamics with $(x_0, \dot{x}_0) = (x_{\text{foot}}, \dot{x}_{\text{apex}})$ and x_{foot}, the phase space tangent manifold is

$$\sigma = \frac{\dot{x}_{\text{apex}}^2}{\omega^2} \cdot \left(\dot{x}^2 - \dot{x}_{\text{apex}}^2 - \omega^2 (x - x_{\text{foot}})^2 \right)$$

where $\sigma = 0$ is equivalent to the nominal manifold.

Optimal Control

Continuous Control: Dynamic Programming

$$\min_{\boldsymbol{u}_{\boldsymbol{x}}^c} \ \mathcal{V}_N + \sum_{n=0}^{N-1} \eta^n \mathcal{L}_n$$

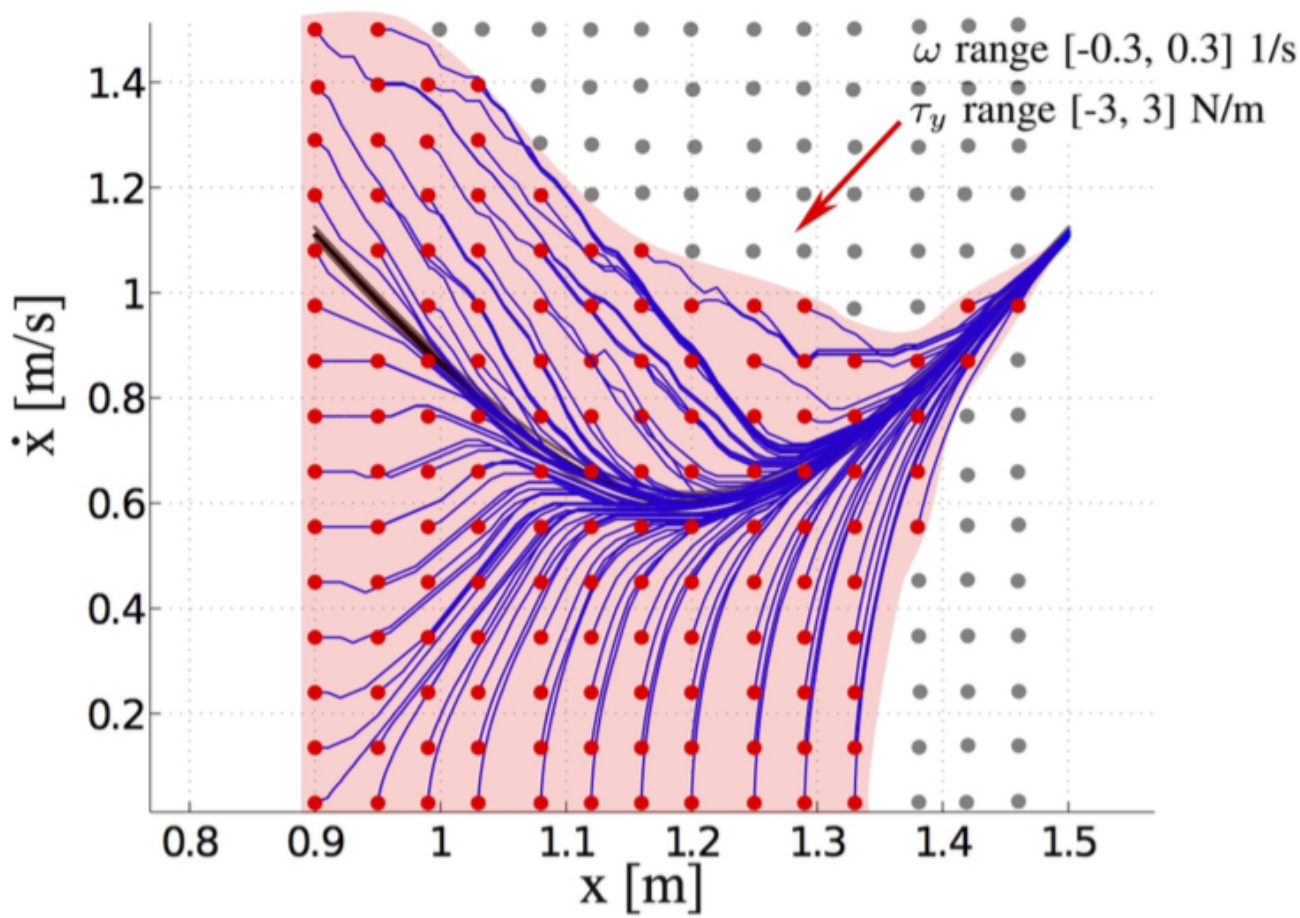
$$\text{subject to}: \ \dot{\boldsymbol{x}} = \mathcal{F}_{\boldsymbol{x}}(q, \boldsymbol{x}, \boldsymbol{u}_{\boldsymbol{x}}^c),$$

$$\omega \in [\omega^{\min}, \omega^{\max}],$$

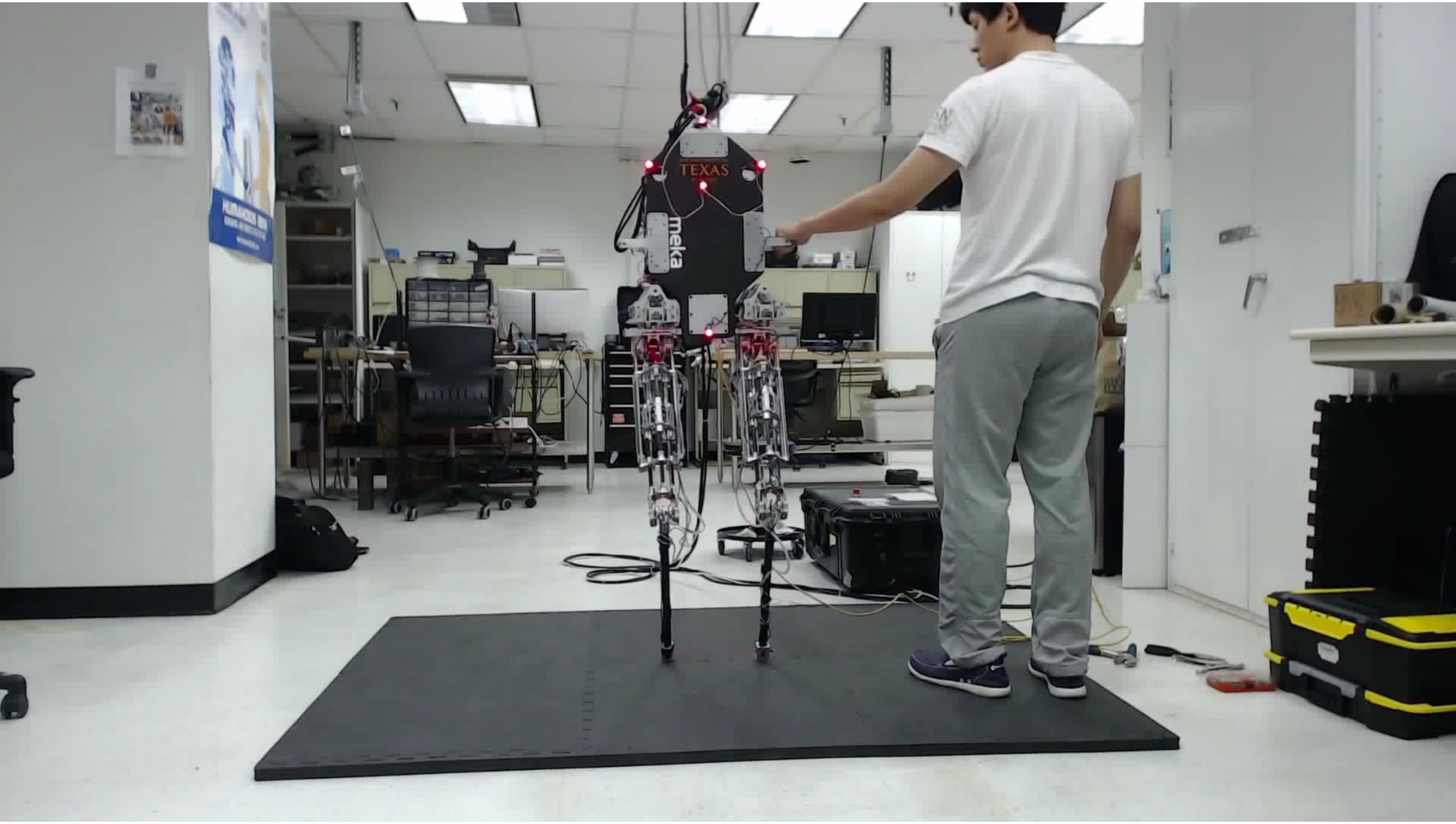
$$\tau_y \in [\tau_y^{\min}, \tau_y^{\max}]$$

$$\mathcal{L}_n = \int_{\zeta_n}^{\zeta_{n+1}} \left[\beta\sigma^2 + \Gamma_1 \tau_y^2 + \Gamma_2 (\omega - \omega^{\text{ref}})^2\right] d\zeta,$$

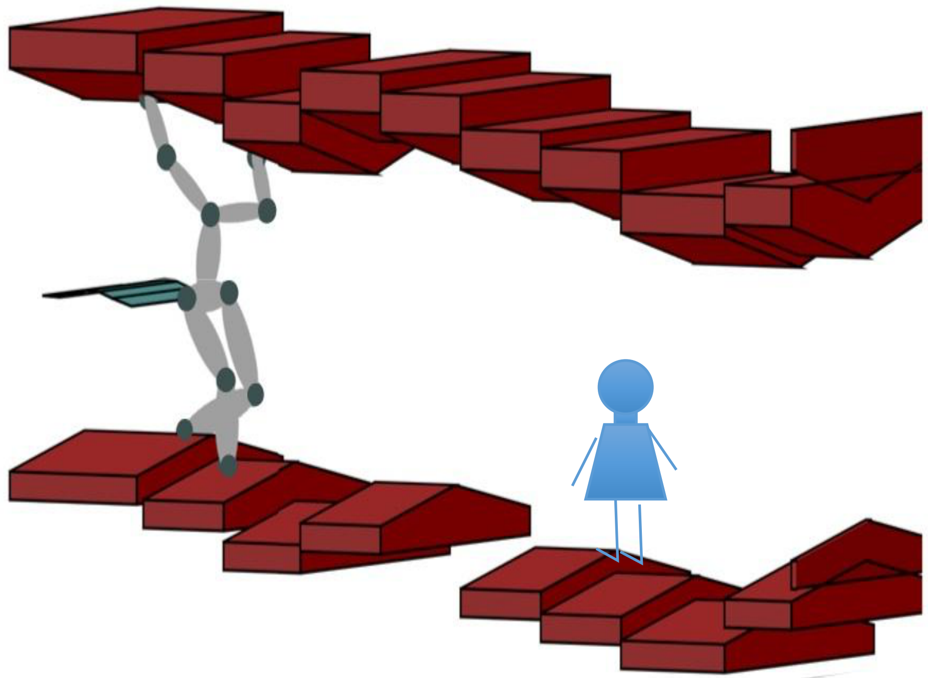
Estimation of Recoverability Bundle



Unsupported Dynamic Balancing



Planner Synthesis



- *Traverse unstructured environments dynamically by using **all limbs**.*
- *React to diverse **dynamic events** by making sequential switching decisions.*
- *Satisfy all the required specifications in a **provably-correct manner**.*

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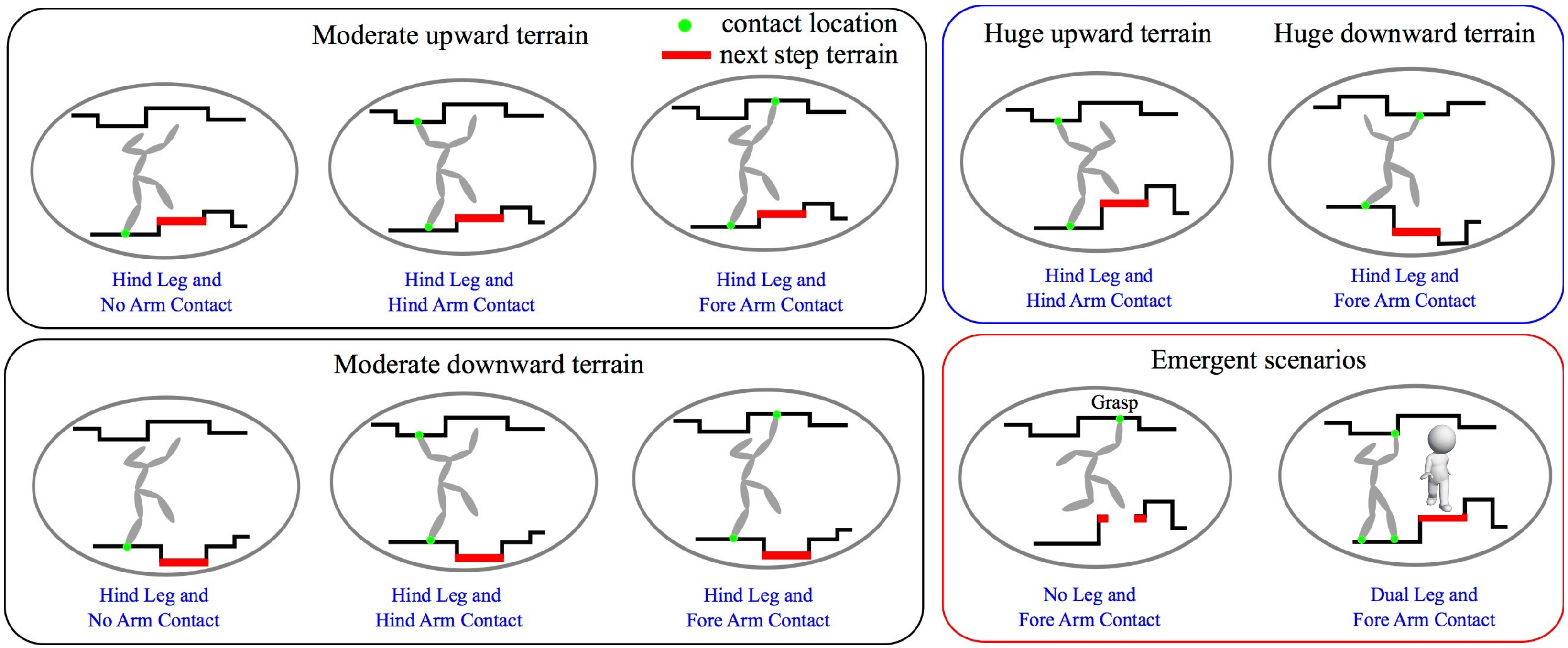
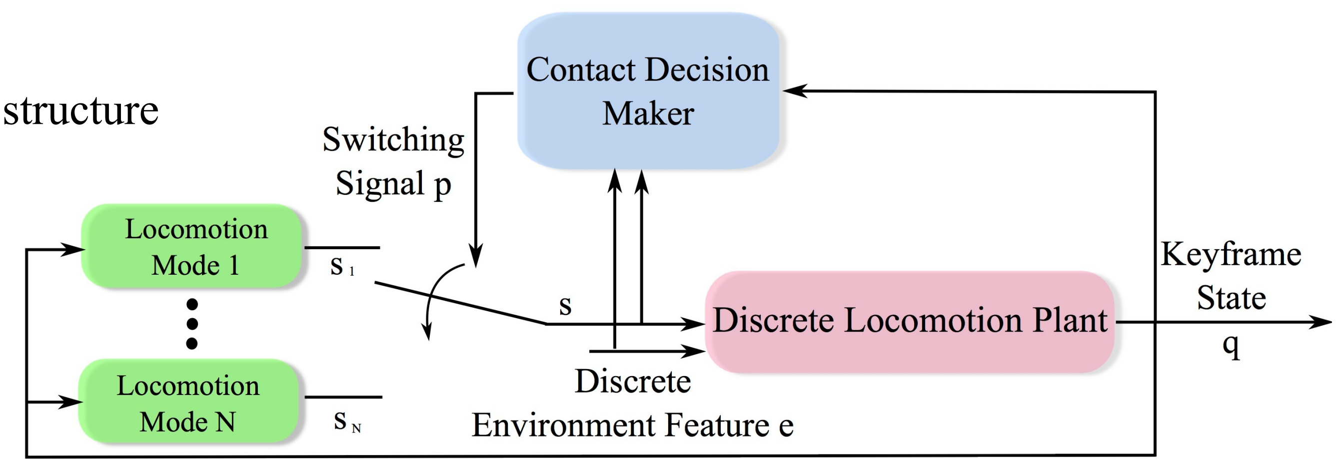
Contact Decisions for Constrained Environments



- Logic based planner structure



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Human Centered Robotics

Temporal Logic For Locomotion

An open finite transition system is a tuple

$$\mathcal{TS} = (\mathcal{Q}, \mathcal{P}, \mathcal{A}_{uc}, \mathcal{A}_c, \mathcal{T}, \mathcal{I}, AP, \mathcal{L})$$

Generalized Reactivity [1] formalism for tractability

$$\varphi_v = \varphi^v_{\text{init}} \bigwedge_{i \in I_{\text{safety}}} \square \varphi^v_{\text{trans},i} \bigwedge_{i \in I_{\text{goal}}} \square \diamond \varphi^v_{\text{goal},i}$$

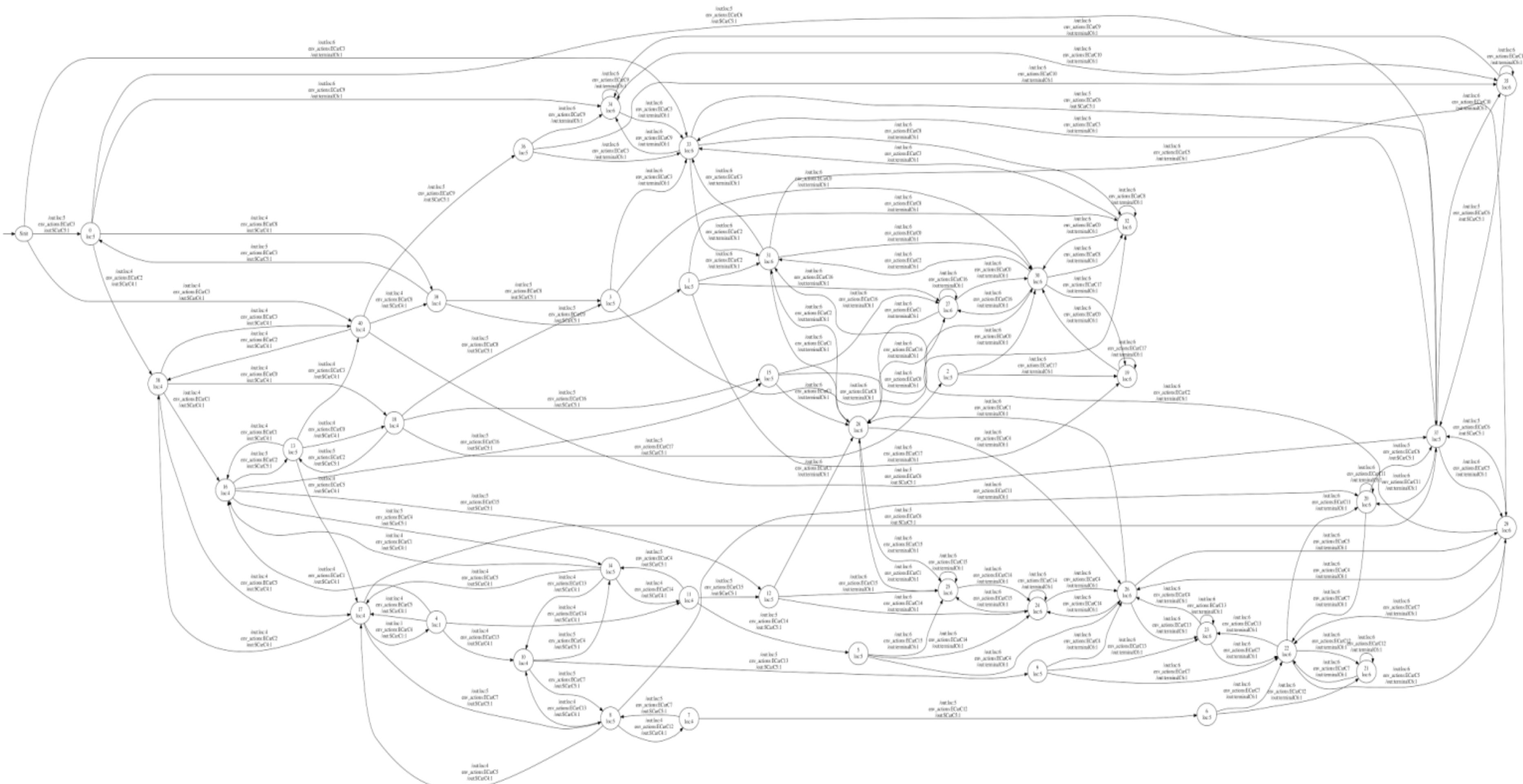
Polynomial Complexity

Final goal of the planner:

$$\varphi := \left((\varphi_q \wedge \varphi_e) \Rightarrow \varphi_s \right)$$

Discrete Contact Planner Switching Synthesis: Given a transition system $\mathcal{TS}$ and a LTL specification φ, this study synthesizes a contact planner switching strategy γ that generates only correct executions (q, p), i.e., $(q, p) \models \varphi$.

Manually creating an automaton would be challenging...



Integrated Task and Motion Locomotion Planner

Human Centered Robotics

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AT AUSTIN

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